# Community Based Energy Efficient Routing Protocol for Pocket Switched Networks

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# Certificate of approval

The thesis titled “Community Based Energy Efficient Routing Protocol for Pocket Switched Networks” is completed under my supervision meet acceptable presentation standard and can be submitted for partial fulfillment of the requirement of the degree MSc in CSE from the department of Computer Science & Engineering, BRAC University.

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# ABSTRACT

PSN (Pocket switched Network) is an emerging research magnet that has been attracting researchers. PSN mainly worked based on the human mobility patterns. In order to make better routing decision PSN consider social behaviors of node. PSN employs human beings as nodes for effective data forwarding. To improve routing performance PSN take the advantages of social characteristics such as community and friendship to assist successful data forwarding. Bubble routing algorithm proposed by Hui et-al, provides an efficient way for forwarding data among different communities. In this thesis, we have proposed an Energy Efficient Routing (EER) algorithm that considers the community concepts and forwarding power of nodes among different communities for effective data forwarding. EER has provide better result on delivery ratio, low cost and low latency in data forwarding than Bubble and some other routing algorithms.

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# List of Publications

1. R.R. Sarkar, K. Rasul, and A. Chakrabarty, (2015) Survey on Routing in Pocket Switched Network. Wireless Sensor Network, **7**, 113-128. http://dx.doi.org/10.4236/wsn.2015.79010

2. R.R. Sarkar, K. Rasul, and A. Chakrabarty, (2015), Energy Efficient Routing (EER) Algorithm for Pocket Switched Network, *International Journal of Computer Science and Network* (*IJCSN*), 5, 80-86.

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# Chapter 1: Introduction

## 1.1 Motivation

Pocket Switched Network (PSN) is an emerging research magnet that has been attracting researchers**.** PSN can be applicable in challenging environments like as remote communication, disaster management, social network analysis, disaster detection, community detection and any intermittently connected networks or where connection is almost broken.

Since the beginning of Internet, Transmission Control Protocol/Internet Protocol (TCP/IP) is the most used network protocol. For years, we know Internet has been successfully connecting communicating devices worldwide. TCP/IP plays most important role for achieving this effectively. The basic principle for end to end data transfer is based on TCP/IP. But when end to end connectivity is broken or intermittent, then TCP/IP may not work properly with reliability, in many cases, it can completely fail to transfer data from source to destination. This problem occurs mainly in remote areas, or villages that lack basic infrastructure to support Internet. In such circumstances, wireless communication networks which are independent of end to end connectivity between nodes can provide better result. One such solution is Pocket Switched Network (PSN). It is a fairly new research area which can work properly without specific infrastructure. PSN is independent of end to end connectivity between humans and it can provide better result in extreme environment which TCP/IP cannot handle. PSN falls into the category of another older network known as Intermittently-Connected Mobile Ad-hoc Networks (ICMANET), which is also popularly known as Delay Tolerant Network (DTN). ICMANET/DTN is one of the well-established areas in the field of wireless communication. This network architecture is proposed that can work properly with limited expectations of end to end connectivity and resources [1]. Networks under this class are potentially deployed in challenged environments using isolated mobile devices with limited resources. It is typically different from traditional mobile ad-hoc networks (MANETs). Because, in an ICMANET, paths between two nodes are intermittent and communication is established only by multi-hop paths between two nodes. That means there is no end-to-end path between nodes. DTN architecture can be applicable for interoperability between and among challenging networks environments (characterized by latency, bandwidth limitation, error probability, and node longevity or path stability). The concept of region and gateway are included in DTN architecture and region boundaries are used as interconnection points between dissimilar network protocols. DTN can be used to change the basic service model, system interface and poor performance presented in some networks.

As mentioned earlier, PSN falls under the category of DTN. PSN and DTN mainly differ in their information carriers. PSN employs human beings for data forwarding, while DTN utilizes any possible carrier, including human beings, to disseminate data. Nowadays, large number of mobile devices is used by people and data collected from them show that "small world" features [2] are strongly existent in them. Small world features is best described by social graph/model theories. Study shows human related network relations are less volatile and long-termed than network depending on simple node mobility. Thus for human-related extreme networking situation, there was need of more social-based DTN than any other types of DTN. From that, the need of PSN was introduced, as PSN is the only type of DTN that uses the knowledge of social characteristics to make better forwarding and routing decision.

PSN is an alternative approach to computer network architecture whose aim is to address the technical issues in heterogeneous network. PSN experience lack of continuous network connectivity and enable data transfer when mobile nodes are only intermittently connected. Since the connectivity is not expected to be consistent in PSN, it employs what is called store-carry-forward mechanism. In this, intermediate nodes carry data packet when they receive it and forward to next node as when contact is established. PSN takes the advantage of human mobility to distribute data from source to destination [3,4]. PSN does not require any assistance of infrastructure. That's why PSN is applicable to rural area and developing regions to realize low cost communications. Mobile devices [5] (like mobile phones, personal digital assistances (PDAs) and laptops etc.) sometime are carried by people in some physical space with high number of nodes and contacts density. Such situation may occur that to individuals at conferences, around office spaces and in case of social communications. Networks that exist in such type of environment are examples of PSNs [6, 7] in which both mobility and multihop forwarding can be supported for communication.

In PSN, efficient utilization of resources such as energy is an important factor for optimum network performance. Due to nodes mobility, frequent contact and message transmission in PSN most of the node's energy is continuously depleted. In this type of network, the amount of energy of a node is considered as an important factor in sending and receiving messages. That means, for successful message delivery node's energy plays an important role in PSN. The lower the energy a node has, the lower its chance to deliver messages through the network. Thus, a proper energy-efficient routing protocol should be selected for message transmission in PSN.

In this thesis we propose a fast (low-delivery-latency) and efficient (both on energy and high-delivery-ratio) routing algorithm named Energy Efficient Routing (EER) that uses the community structure for message forwarding. Here, we evaluate EER only on SASSY dataset and in this thesis we evaluate EER both with SASSY and Synthetic SASSY dataset and also compare EER with BUBBLE [8], which is a well-known social based algorithm and some other algorithms.

Outline of the thesis: In chapter 1, we introduce PSN, its features, challenges and applications. In chapter 2, we represent and categorized all the work related to PSN. The overall working methodology of this thesis is described in chapter 3. It includes a details discussion about our proposed algorithm, dataset, custom simulator and comparing algorithms and metrics. In chapter 4, we represent our experimental results and chapter 5 ends with conclusion and direction for future works.

## 1.2 Features of PSN

PSN takes the advantages of both human mobility and also intra-networks or internetworks to transfer data. PSN has been created to provide network services for mobile users in such places where they are localized truly between Islands of connectivity. There is huge amount of portable devices such as laptops, PDAs and mobile phones, active on localized wireless bandwidth (like Bluetooth), storage capacity and CPU power. The only resource needed to run this portable device is power. With first development of power engineering and advancement in battery technologies, once charged it is possible for portable device to last for a week, while remaining in constant network contact. We expect that this innovation will continue, allowing devices to participate in wireless networks while minimizing power consumption. In case of increasing the rate of successful forwarding in PSN, data may travel through via multiple nodes. With development of technology memory has become cheap and accessible for all. However, in PSN nodes do not only carry their own message but store-carry-forward other nodes' messages as well. So, efficient memory management is a necessity here.

In this type of network, nodes may be mobile or fixed devices within a certain location [9] like a computer with blue tooth, a laptop with a Wi-Fi network, a mobile phone etc. Nodes usually refer to any network enabled component that has the property of receiving and forwarding messages. The main objective of PSN is to make the use of every communication opportunity, and the physical mobility of the devices for transporting data from the source to destinations in situation where there might not be any base station or central hub. Some features of PSN problem space are described as follows.

### 1.2.1 Store-Carry-Forward Approach

In PSN, network links may be disrupted for a long time, therefore end to end paths are assumed not to exist. That's why store-carry-forward mechanism is the main mechanism for data delivery and main-objective of routing to achieve maximum delivery ratio. This mechanism's is a real life analogy is postal service. In postal service letters are passed through several post offices, then they are processed and finally forward to their desire destination. This store-carry-forward method works similar to the concept of postal services. In store-carry-forward mechanism message or a chunk of message is forwarded and store in the nodes until it successfully reached to its desire destination. Figure 1.1 shows a graphical representation of store-carry-forward approach and also shows how message or a chunk of message is propagated through a network. In this figure, the circle represents a node and the box represents its storage capability. So in Figure 1.1, each node is relaying its messages to its desire destination and also has storage to store message or a chunk of message, until the message/messages has reached its destination or the node has meet another suitable node.

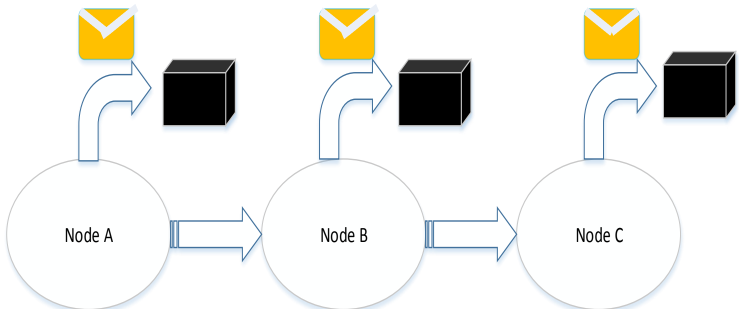


Figure1.1 Store –carry –forward approach

### 1.2.2 User Mobility

Human mobility plays a key role in PSN. Mobility gives rise to new localized opportunities. User mobility also increases the use of network bandwidth as large amount of data needs to be carried around the network. The probability of node mobility is measured by using different mobility model. Some of the models are briefly discussed below:

1) Random waypoint model [10] is one of the most popular model of this category. In Random waypoint model, a node randomly chooses destination (waypoint) and moves towards the destination. In this model nodes are distributed over the simulation area randomly and they stop for a constant time. After the completion of waiting period each node chooses a waypoint (destination). Random waypoint model is used to simulate of wireless communication networks for humans and also used to represent cellular structured network. Other different approaches like the random-direction model [11], random-border model [12], and the modified-random-direction model [11] are various type of fully random movement with different node density distributions.
2) There are also different categories of mobility models [13]. Like, Manhattan-grid model [14] where initially nodes are randomly distributed on the streets (total simulation area is divided into several square blocks named as streets).Each node chooses a direction and a velocity. If a node reaches a corner, then the node changes direction with a certain probability. The velocity of node is also changed over time.
3) Obstacle mobility model [15, 16] is another mobility model that use Voronoi-diagrams to determine optimal path. The movement using this model is more realistic, but there is still no movement on optimal paths.

4) Reference-point-group-mobility model (RPGM) [17] model the movement of groups of nodes according to an arbitrary mobility model. According to this model, the actual position of a node is a random movement vector added to the position of node's reference point that is assigned to it. According to the arbitrary mobility model, the actual position of the node's reference point may change but the relative positions of the reference point inside a group do not change.
5) Clustered-mobility [18] is a mobility model that follows random based movement and uses similar approach as random waypoint model. The difference is that the attraction of a point depends on the amount of nodes nearby .This model is applicable in different tactical scenarios.
6) Gauss-Markov model [19] is another example of mobility model. According to this model node's velocity and direction of the future depend on the current value. The new values are chosen based on a first order autoregressive process.
7) Smooth-random model [20, 21] is a mobility model where nodes are classified concerning their maximum velocity, preferred velocity, maximum acceleration, and deceleration. Velocity and direction may also be chosen by correlation among each other. By doing so, more realistic movements may be realized.
8) The area-graph-based mobility model [22] realizes sub-areas with higher node density. This model also realize paths between higher node density and lower node density. The sub-areas are considered as vertices of the area graph and the paths are considered as edges. A weight or probability is assigned to each edge. A node moves inside the sub-area for a randomly chosen time according to the random-waypoint model. After this time, node chooses one path according to probabilities at the edges. Next, the node moves on the path to the next area.
9) There are some mobility models that can be applicable on social networks. The social-network-founded mobility model [23] is one of them. This model is based on interaction indicators among all pairs of nodes. If a node has larger interaction indicator, then the probability of social relationship of the node becomes high. Firstly, according to the nodes interaction indicator, they are grouped in clouds. Nodes are moved inside the clouds according to a random waypoint model where the waypoints are chosen

according to the interaction indicators. Community based mobility model [24] is used for the classification of the nodes into groups and their movement inside the clouds.

Due to mobility of nodes, forwarding paths becomes unpredictable and probability of mobile reachability becomes highly dynamic, thus mobility introduces new challenge to PSN.

### 1.2.3 Opportunistic Networking

Opportunistic networks are a very promising networking field. In opportunistic networks nodes build a self- organizing ad hoc network without requiring any pre-existing infrastructure [25, 26]. In opportunistic networking, nodes opportunistically exploit these contacts with other nodes to exchange messages to the appropriate destination. In opportunistic network nodes are able to make communication with each other even if there is no route exists to connect them and also collaborate them to exchange data from the source to destination [27].

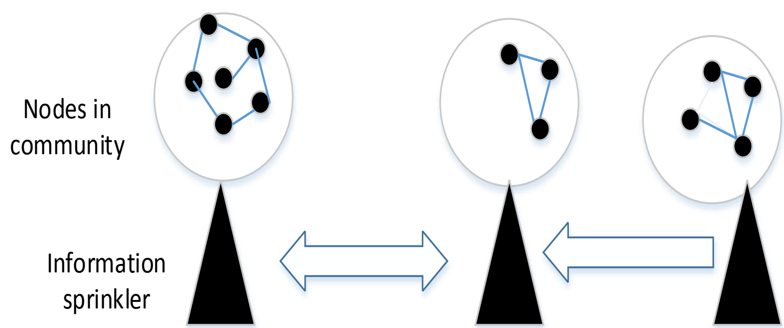


Figure 1.2 Opportunistic Network

Figure 1.2 shows the basic structure of an opportunistic network. As movements in PSN are not pre-defined thus a neighbor is met is only by chance and collaboration can happen only as opportunity arises. In this type of network, at first a node has to find a neighbor node for starting collaboration. Then they start to exchange data. Nodes pass data to its neighbor node that it has discovered. Data is distributed among all nodes through information sprinkler. Information sprinkler is a dedicated node, which is less likely to be mobile and works like any other opportunistic network nodes. It uses data sharing protocol. The information sprinkler can collect information from other nodes whenever these neighboring ,nodes belonging to sprinkler's community or any other community, approaches the sprinkler and then the sprinkler distribute the information to other information sprinkler within a short time period. That means in this opportunistic network messages are distributed hop by hop towards the destination.

In case of data forwarding in PSNs, internetwork links are crucial. Both the intranetworking and internetworking opportunities allows PSNs to provide highly robust networking for users, to transfer data. That means opportunistic networking allow users to make communications with each other in such unavoidable circumstances and also use physical movement of the user to transfer important messages.

### 1.2.4 Social Properties

As already mentioned earlier, small world features or social properties are strongly evident in PSN [2]. This is because, PSN comprises of human and humans happen to be social being, one such social nature is the ability to form social graph from the data obtained through PSN. A social graph is a global map which shows how nodes are connected. It is also gives insight to many other social metrics like friendship, community, centrality and modularity. Most of these terms can be found in the work on graph theory by Girvan and Newman et al. [28]. Some definition of common social properties found in PSN are described briefly below:

a) For PSN social graphs, each vertex represent a person carrying device and each edge represents frequency of interaction between these devices.
b) Centrality is the measure of how important a node is or how a node can helps connect other nodes in the graph. A node with high centrality value represents a strongly interacting node, which can be a good candidate for being data carrier to other nodes. For example betweenness centrality of a node measures the number of shortest path passing through it. Higher the betweenness centrality value, better bridging node it is for data exchanging purpose.
c) Similarity value can also be found through social graph. Similarity is the measure of number of common neighbor between individual nodes.

d) Friendship is another concept from sociology which refers to personal relationship between individual nodes.

e) Modularity which is a function that calculates the quality of newly formed communities within a network. In that process community formation, modularity can be used to decide whether to further divide a network into newer communities or to keep it as it is.

## 1.3 Challenges of PSN Routing

PSN can be defined as a communication paradigm that can take the advantages of human mobility and intranetwork or internetwork connectivity. As continuous end to end connectivity is absent so successful delivery of data becomes difficult. Here in this section we will discuss about some challenges which we may face in successfully deployment PSNs. These challenges are also beacons for researcher, willing to improve PSN, to work on.

### 1.3.1 Mobility

PSNs are formed of human communities. So it must include mobility. That means node mobility is an important issue in PSN. In PSN, it is difficult to build end to end paths for delivering message from source to destination, because user's undefined mobility is an issue here. Due to the node mobility, it becomes unpredictable to meet a node with other nodes in the network. That's why continuous end to end connectivity is hardly possible. That means, routing in such network means finding temporal path between sources to destination [29], but finding an efficient path between sources to destination, i.e. successful routing of data without proper knowledge about the dynamic network topology, is a difficult task [30].

### 1.3.2 Selfishness

As PSN is formed by human beings and they are selfish in nature. Human operated devices forming a PSN may not be willing to forward data for others, except their own desired destinations. PSN's store-carry-forward nature requires nodes to be willing to carry other's data but the presence of selfish nodes causing a great challenge in successful data transmission. So, necessary mechanisms should be employed to encourage the node to forward data and get rid of their selfish behaviors.

### 1.3.3 Data Forwarding

In PSN data forwarding are occurred based on some policy, as it supports both of intranetworking and internetworking. In the case of local connectivity, nodes forward messages according to the knowledge of their local environment. But to acquire accurate knowledge about the entire local environment is a key challenge because PSN is independent of any predefined infrastructure. As PSN has some limitation on resources, so availability of storage and energy are also the key challenges here.

In PSN, data are forwarded to the carrier nodes that are close to destination. But the main challenge is in the development of a method that will appropriately determine a carrier node, which will provide good forwarding opportunities to the destination, for a given message.

When global connectivity is available, a node forward messages directly to other suitable nodes that are globally connected. Finding which nodes are globally more strongly connected is also a challenge in volatile dynamic infrastructure-less network environment.

### 1.3.4 Security

In PSN routing take place by the collaboration, dependency and cooperation among nodes. Nodes have to collect and exchange messages among themselves. In that case, nodes may face different security issues. As messages are exchanged among number of nodes, so it may be altered, affected or modified by a malicious relay [31]. On the other hand, some other security problem may occur such as redirection, eavesdropping, denial of service, fabrication, poisoning etc. So incentive mechanism, like those found in [32] for Wireless Sensor Network, should also be developed for secure and safe delivery of messages and for preserving user's privacy in PSN.

### 1.3.5 Scalability and Clustering

Most of the routing protocols in PSN are flat. This flat approach is suitable for small network but is not scalable .In this case, clustering may provide a better result that can make groups among the mobile nodes with similar mobility pattern into same cluster. So, nodes belonging to same cluster can help each other to reduce overhead, make routing scalable and also share of resources. Clustering approaches can be useful to unfold large networks into different communities [33]. In order to uncover overlapping nodes in complex networks, clustering approach based on particle walking and competing with each other by using random deterministic movement [34] can be used. Another type of clustering technique is discussed in the paper LABEL [35]. According to LABEL, each node within a community is assumed to have a label that informs other nodes about its label. It provides proper knowledge about the communities to forward messages from source to destination and significantly improve the forwarding efficiencies. Overall clustering is a very important field that has lot of scopes to research on. It is undoubtedly an important open issue for future work in PSN.

### 1.3.6 Energy and Storage management

Mobile devices that are carried by human beings have very limited energy and storage capacity. For rapid and reliable data transmission it becomes unreasonable to utilize large amount of storage and energy. Existing PSN routing protocols do not consider low energy consumption and low storage space in their design objectives. These energy and storage management can be an effective metric to evaluate routing in PSN.

## 1.4 Applications of PSN

The main objective of PSN is to survive complex and challenging network environment. This includes surviving hardware failure as well as software or protocol failures. As PSN do not require the assistance of any infrastructure, they are applicable in rural and developing regions to allow low cost communication. PSNs can provide efficient communication in place where internet connectivity has disrupted due to infrastructure fails. Some applications of PSN are given below:

### 1.4.1 Remote Communication

There are many rural communication projects in remote villages to provide the access to Internet. Some of which is try to reduce the cost of communications using the way of asynchronous information transmission. For example, Wizzy digital courier service[1] provides Internet access for some village schools in South Africa. DAKNET [36] project focused on

[1] Wizzy digital courier. http://agln.aspeninstitute.org/projects/wizzy-digital-courier

providing low cost Internet services to the rural areas of India. It is suggested the use of physical means for delivering messages to areas which are not connected via traditional networks.

### 1.4.2 Disaster Managements

There are some models that are used for security and disaster communication, search and rescue communication. For example, post disaster mobility model [37] is used for this purpose. This model includes the impact of disasters on the transportation network and models for human and relief vehicle movement.

### 1.4.3 Social network analysis

PSN can be used for analyzing social network. Many research areas, starting from anthropology to E-commerce to engineering, need social network analysis [38]. As PSN deals with people, it can be used to collect data among social entities and then use them to further understand implications, relationships and patterns among peoples, which then can be used to develop new applications for different usages.

### 1.4.4 Disease detection

These days using PSN to understand how epidemic diseases spread is a common tool in the field of epidemiology. PSN helps to track people to collect data for understanding disease, as simple as Flo to deadly as HIV, is spread. One such work is done by Hashemian et. Al [39].

### 1.4.5 Community detection

Community detection is a very common use of PSN. From the data collected using PSN, communities having higher modularity are often grouped together. Works that have done this are refereed in [40] and [41]. Another application of community detection through data tracking using PSN could be used to detect terrorist movement in inhabited jungles or deserts. Another use of Community detection through PSN could be to provide securer access control in social network by finding groups of people who help to spread spams in social network. Such work is done by Grier et al. [42].

# Chapter 2: Related Work

## 2.1 Literature Reviews

In this chapter we represent different routing protocol of PSN. We also categorized these routing protocols in four board categories which are flooding based protocol, direct pass, probabilistic model based protocol and social network based protocol. We include some popular PSN routing protocols in these categories. All these categories are discussed below:

### 2.1.1 Flooding Based Protocol

Flooding based protocol is one of the category of routing protocol used in DTNs, passed down to PSN. Epidemic routing [43] falls in the category of flooding based protocol. This protocol mainly work based on the replication of messages. Messages are distributed to every node present in the network, with an aim for messages eventually reached their destination. Epidemic routing protocol guaranteed successful transmission of messages. The main benefit of this routing protocol is that it has low latency in case of message delivery. This protocol increases the overhead drastically in terms of traffic congestion and energy. Different versions of the epidemic routing protocol [44], [45] have also been proposed in order to reduce message overhead by considering different constraints such as time limit, maximum hop count, forwarding probability, or applying different techniques to inform nodes about the successful delivery of the message. Another benefit of flooding based protocol is that it does not require any prior local or global knowledge about the network. In this protocol messages are continuously replicated to every node in the network that results high overhead, consumption of energy and traffic congestions.

Flooding based protocol can also be based on tree structure [46]. Here the decision of how to make copies of message and ensuring the number of copies of message is an important issue. Two hop relay [46] is another category of flooding based protocol. According to this protocol, if there are n nodes around the source are directly connected to the source node, then *n* copies of message are generated to the source and transmitted to those nodes. Spray and Wait [47] routing protocol is an example of variation in this category. According to this protocol in spray phase a number of message copies are forwarded by the source node to the same number of other nodes (known as relays). In wait phase of this protocol, if destination is not found in the spraying phase each of the node carrying a message copy will forward the message only to its destination. These protocols can provide better result with respect to average message delivery delay but at the cost of huge number of transmissions per message delivered. Flood based protocols are simple to implement in order to achieve good performance.

### 2.1.2 Direct Pass

Direct Delivery Routing [48] protocol falls in the category of direct pass. It is the simplest protocol to transmit message or a chunk to its desire destination. In this protocol a node called as source node will deliver message only to destination node is encountered by it. So direct communication between source and destination node is necessary for successful delivery of message. No relay node is necessary here for successful delivery of message between source node and destination node. Here, in the Figure 2.1, we can see a graphical representation of direct delivery routing approach. In this figure, node A has a message to deliver and according to the direct pass approach when Node A encounter the desire destination then it will deliver the message.

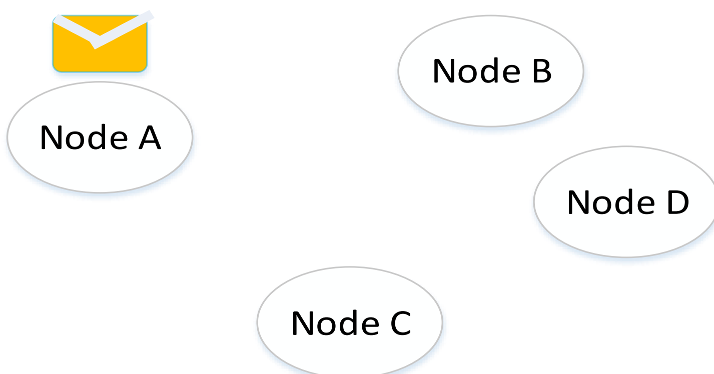


Figure 2.1 Direct Delivery Routing

This routing protocol always select the direct path for message delivery between source and destination. Direct delivery routing protocol does not require any information about the network. Because of this simplicity, this protocol does not need to consume too many resources. However this direct delivery routing protocol only works, when source node and destination node comes into direct contact with each other and is accompanied by huge delay.

First Contact Routing [48] is another type of direct pass routing protocol. In this protocol the relay node that come to first contact to the source node work cooperatively to increase the probability of successful message delivery. First contact routing approach also increase the use of bandwidth and storage. It has same advantages and limitations of direct pass routing algorithm.

### 2.1.3 Probabilistic model based protocol

Probabilistic model based protocol is another category of routing protocol that is effectively used in PSN. PROPHET [49] routing protocol is a popular example of this category. This protocol is mainly proposed in order to increase the delivery probability in a social network. According to PROPHET if a node visit the same place several time, then there is a probability to repeat this in future. In this protocol each node use a metric called probabilistic metric in order to deliver message to a reliable node. When two nodes meet, they exchange their stored information which contains delivery probability and encounter related information. Here the probability of message delivery can be calculated by using transitive delivery probabilities. When *node i* and *node j* meet one another and their elapsed time unit is *k* then the delivery probability can represented by the Equation (1) below.

$$P_{i,j}(k+1) = (1- P_{i,j}(k))* P_0 + P_{i,j}(k) \tag{1}$$

In this protocol forwarding decision is made based on the delivery probability and a message is delivered to a node with high delivery probability to reach the destination. PROPHET has lower overhead, small use of storage space, reduce power consumption and also increase the probability to deliver message to its desire destination than routing protocols of other categories. But in PROPHET average delay is increased to deliver a message from the source to destination. In this protocol forwarding decision is made based on the delivery probability and a message is delivered to a node with high delivery probability to reach the destination.

A similar probabilistic approach is proposed [50] to improve the performance of PROPHET routing protocol. This approach is based on predictability concept to remove message delivery delay and number of message drop. In this approach, an improvement factor is include in the probability calculation equation of PROPHET in order to improve the above mentioned factors.

MaxProp [51] routing protocol calculate the maximum probability of messages to be delivered. Messages in the buffer are prioritized. In this protocol the hop count value is lower and probability set is higher. According to this protocol the priority of packet is determined by calculating the probability of nodes meeting when hop count value exceeds the threshold value.

Plankton [52] routing algorithm also falls in this category. It is possible to improve routing performance in such type of network by controlling through message replication based on reliable contact prediction. Plankton consider two key ideas to predict contacts. Firstly, it classified the communication links into weak link or strong link. This classification is based on how successful a message is delivered to its desire destination using links. Secondly, strong links are identified based on the associative relationships that are observed in different time. In order to deliver a message it firstly assign an initial replica quota and target delivery probability. Plankton controls message replication when message is duplicated to a node that has high contact probability or high delivery probability. Plankton reduces overhead by controlling replicas and also estimates contact probability in order to improve routing performance. It also dynamically adjust replication quota by estimating contact probabilities and delivery probabilities.

Context-Aware Adaptive Routing (CAR) [53] uses prediction to allow efficient routing. If a host want to send message to any other host it uses a Kalman Filter prediction [54] and multi-criteria decision theory [55] to choose the best next carrier for the message. Kalman Filter prediction techniques were originally developed based on automatic control systems theory and used in CAR to achieve more realistic prediction of the evolution of the context of a host and to optimize bandwidth usage. Multi-criteria decision theory is used to estimate overall delivery probability. According to CAR if both sender and receiver are in the same region of network then forwarding path is determined by synchronous routing protocol. If a message cannot be delivered synchronously then the best carrier for a message is chosen based on calculating the highest delivery probability that is synthesized locally context information.  CAR reduces overhead in terms of the number of messages sent and can provide good performance. In dynamic environments, as the number of undetected nodes increases, the overall predictability level increases. This is a limitation of this protocol.

### 2.1.4 Social Network Based Protocol

Social Network based protocol is another category of routing protocol. Social network based protocol focuses mainly on social network features of humans for making routing decisions. Social structure helps to build forwarding paths, allowing two nodes to communicate over time using opportunistic contacts and intermediate nodes [56]. Human belongs to different communities' altogether make human society. This concept is used to build different type of social network based protocol. Routing of messages among different nodes (any network component that has the ability to receive and forward message) in PSN is occurred by detecting community structures throughout the network. Routing protocols that take this human community concept into consideration are fall in the category of social network based protocol.

Bubble-Rap [8] protocol fall in this category. It considers social network for making forwarding decision. In Bubble–Rap there are two important metrics through which nodes of the network is ranked. These two metrics are local ranking and global ranking. Local ranking of individual nodes means the popularity of the node within its own community. Global ranking indicates the popularity of an individual node within the whole network. Bubble-Rap protocol works based on two assumptions and these are: each node must belongs to at least one community and each node must has a global ranking and also a local ranking. According to Bubble-Rap if the source node and destination node are in the same community, then firstly it checks whether the encountered node is also in the same community, if so the local ranking of the source node and encountered node is checked and if the local rank of encountered node is greater than the local rank of source node then the message is forwarded. If the source node and destination node are not in the same community, then this routing protocol is forwarded to the encountered node if the encountered node is in the same community of the destination node or if the global ranking of encountered node is higher.

Figure 2.2 shows an illustration of Bubble Rap forwarding from source (S) to destination (D). Here, source (S) and destination (D) nodes are specified by black color. On the other hand, black and green arrows show the Bubble Rap operations based on global centrality in global community and local centrality in D's community respectively.

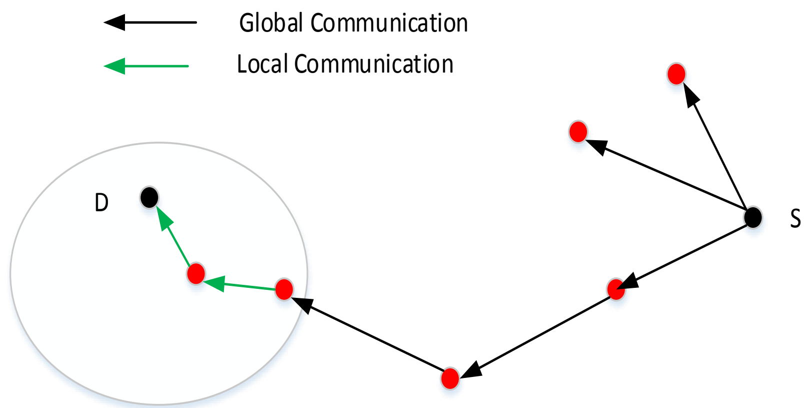


Figure 2.2 Illustration of Bubble Rap Routing

Lobby Influence [57] is also fall in the category of social network based routing protocol. In this protocol message forwarding decision is made by considering the local and global popularity of the nodes and their lobby index. Lobby index is measured by the strength of the relationship with neighbor nodes. Lobby influence protocol allows more popular nodes to forward message to the less popular node that has high lobby index in the network. Lobby Influence protocol is an enhanced work of Bubble-Rap protocol. The main difference between these two protocols is in their forwarding decision. As we discussed earlier Bubble-Rap takes forwarding decision based on the node popularity. On the other hand, the forwarding decision of Lobby Influence depends not only on node popularity but also on Lobby index. In this protocol there is consider three assumptions and they are

1. Each node must have a label and must associate with at least one community.

2. Each node has one global rank and one local rank to identify global and local centrality. But a node may have multiple local rank and multiple label.

3. Each node has its lobby index that indicate the strength of the relationship with its neighbors.

This protocol increase the probability of message delivery and at the same time decrease overhead of more popular nodes. Another similar work that builds on [56] is discussed in [58] and this focuses on betweenness centrality value to enhance Bubble-rap's global routing decision.

Another social network based routing protocol is SimBet [59]. According to this protocol when two nodes meet one another, they are compared with one another by using SimBet utility. SimBet utility is a combination of similarity utility and betweenness utility. Similarity utility means number of common neighbors between a node and the destination. On the other hand, betweenness means number of indirectly connected nodes one node can link. That means these utilities can be estimated by the statistics of the direct links between itself and other nodes in the network. When two nodes meet they exchange their contact information with other and then determine SimBet utility to destination node. As a result the number of node and amount of exchanged data are proportionally increased. In SimBet routing, when node n, carrying a message for destination d, meets node m, n calculates betweenness and similarity value of node m. The functions used for calculating Similarity is shown in equation (2) and Betweenness centrality are given in Equation (3) below.

$$SimUtil_n = \frac{Sim_n(d)}{Sim_n(d)+Sim_m(d)} \quad (2)$$

$$BetUtil_n = \frac{Bet_n}{Bet_n+Bet_m} \quad (3)$$

PRO [60] profile based routing protocol is another example of social network based protocol. PRO use community structure of social network, in order to cover maximum number of community to reach the destination.

In PRO nodes who belong to the same community is called as local neighbors and nodes that are connected to other community is called as remote neighbors. PRO works through the regularity of inter – contact events between nodes. This regularity is measured in terms of meeting duration and number of meeting between nodes. In PRO each node maintain a local observation table which keep track of periodic intercontact events and updates the observation score. Observation score can be defined as a metric that indicate the probability of observing a node periodically. In case of forwarding PRO gives priority to the observation score. The nodes that observe the destination node regularly are more suitable candidates for forwarding directly to destination.PRO also checks the information dissemination score of nodes in the communication range. If the current nodes encounter another node, which is known as candidate node, having higher information dissemination score than the internal threshold score of the current node, then the message is forwarded to the candidate node. PRO also controls the number of copies for each message that can be forwarded by single node which is known as Forwarding-Quota.

PRO achieve fast and efficient routing in intermittently connected PSNs. That means PRO has low-delivery-latency and low-message-overhead. PRO is also self–learning, completely decentralized and local to nodes but sometime it can be costly.

CAS [61] Community-based Adaptive Spray routing protocol is also falls in this category. This protocol mainly based on two aspects, firstly, this protocol select the intermediate nodes that are closest to destination and secondly, it dynamically control the number of message copies according to taking into consideration the time-to-live of a message. According to the community graph firstly this protocol find the shortest path to destination. In order to find gateway node gateway table is used here. The gateway table contains community ID, gateway node ID, the ID of the community that is connected by the gateway node, average inter contact time between gateway node and community and also a timestamp of last update of the table. Then optimal number of message copies needed to route is calculated. The gateway node is set as an intermediate target node and route specific number of messages. If the gateway node is the destination node then the process is ended. According to CAS, if a node is carried message of $L>1$ ($L$ is the number of message copies permitted to route the message to the intermediate target node) copies and encounters another node, then it checks whether this encountered node is inside its community. If they are in the same community, then it checks whether this encounter node is the intermediate target node. If so then the message is forwarded to the encountered node. Otherwise, $L/2$ copies of message is forwarded to the encountered node and the remaining copies of message is kept by the source node. If they are in different community then it checks whether the encountered node is the destination node, if so then copies of message is forwarded to the encountered node. The main goal of improving routing performance is to increase the delivery ratio and minimize resource consumption. In order to achieve this goal Community based adaptive spray (CAS) considers both of the mobility pattern and time–to-live of message. According to this time-to-live CAS dynamically control the number of message copies.

SANE [62] social-aware stateless forwarding is also an example of social network based protocol. In case of routing in PSN, SANE takes the advantage of both social aware and stateless approaches. SANE supports two communication services unicast and interest-cast. According to interest-cast a message should be forwarded to individuals whose interest profile closely resembles to destination. That means according to this service a user can communicate a certain information to the maximum possible number of interested users, within a certain period of time. According to SANE a message has a header that contains a target interest profile, which is also known as message relevance profiles, this is an integer value that represents the number of replicas of the message that is allowed to a node to forward to other nodes and a time-to-live value. In human society individuals with similar interests often meet one another than individuals with reverse interest. This concept is used in SANE and then according to the above observation social-aware and stateless forwarding mechanism is designed.

Friendship based routing [63] is a social network based routing protocol in which forwarding decisions of messages are made based on temporally differentiated friendships. This protocol firstly identify accurately the relations between nodes by considering a metric named social pressure metric (SPM) that motivate friends to meet to share their experiences. SPM considers three behavioral features of close friendship high frequency, longevity and regularity. Secondly, Local community is formatted by considering link qualities from nodes contact history. A node can define a community as a set of nodes with link quality itself larger than a threshold. This community will include only direct friends. But two nodes that are not directly close friends still can be close indirect friends. So finally, this protocol identify the way of handling temporal differentiations of node relations by allowing different friendship communities in different periods. In case of forwarding, if a *node* i have a message for *node d* and meets with *node* j. Then i forwards the message to *j* if and only if j and d*'s* current friendship community is same and j is a stronger friend of *d* than i. i will not forward the message , if j and d are not in the same friendship community but j has better link with d. This protocol can achieve better delivery ratio without maximizing the cost compared to other protocols. As this protocol allows different friendship communities in different period, it may require more space and that can increase cost.

In order to increase the performance of social network based protocols in large scale networks community aware framework (CAF) [64] can be used. CAF can be easily integrated with some of these social network based algorithms. This framework extension relies on the fact that social forwarding algorithms normally operates within the same sub-community. Here particular nodes are defined as MultiHomed (MH) nodes (nodes that belongs to multiple sub communities) who circulate the message to other sub-communities. These MH nodes are ranked by the number of sub-communities they belong to (MHrank). CAF mainly relies on local social/contact information to predict future transfer opportunities. By integrating CAF with forwarding algorithm may increase delivery ratio, but sometime it can be costly.

# Chapter 3: Working Methodology

## 3.1 Design Issues

PSN comprises of human and humans happen to be social being, one such social nature is the ability to form social graph from the data obtained through PSN. A social graph is a global map which shows how nodes are connected. It is also gives insight to many other social metrics like friendship, community, centrality and modularity. Most of these terms can be found in the work on graph theory by Girvan and Newman et al. [65]. Some common social properties of PSN are already discussed.

PSN devices have resource limitations in memory and computational power and the usage of energy is also critical [66]. Packets possess a Delay Tolerant property encoded in TTL [67]. These assumptions motivate us to emphasize delivery ratio and proper utilization of resource. Energy saving and increased delivery ratio at low cost is beneficial.

## 3.2 Community Detection

Community is an important social property of PSN. Community is an assemblage of two or more people occupying the same geographic area. Community is usually defined as a group of interacting people living in a common location. A member of a given community is more likely to interact with another member of the same community. Actually social relationships among people are clearly represented by communities. As PSN employs human beings for effective data forwarding, so community detection is very common use of PSN.

Our proposed algorithm EER uses community concepts for data forwarding. Different type of algorithm has been used for community detection. K-Cliques is an example of community detection algorithm and was used in BUBBLE [8]. It requires the minimum size of communities to be specified prior to forming the communities. We use Louvain algorithm [33] to detect communities among nodes. Communities are characterized by frequent contact. Louvain clustering algorithm is fast and simple to implement and does not require a predefined community size. It works with multiple iterations and two different phases. In the first phase, each node is considered as a separated community. After each iteration, every node is selected and merged with its neighboring communities and check the network modularity. If the network modularity does not improve, then the algorithm stops. In the second phase, new community is formed whose nodes now the communities are found during the first phase. These two phases are repeated until local optimal point is reached. Louvain clustering algorithm formed communities for EER and helps to avoid isolated individuals. Our future work will compare routing performance with different clustering algorithms.

## 3.3 EER Algorithm

According to EER firstly communities are detected among all the nodes. We have divided the EER algorithm into two parts. In first part we consider intra-communication of nodes which actually means communication among nodes who are belong to the same community. This type of communication is also known as local communication. Second part of EER is inter-communication among nodes who are belong to different communities which is also known as global communication. This will help to determine whether a message will be forwarded or not. For this algorithm, the following assumption is considered:

- Each node must belong to at least one community.
- Each node has its "Forwarding Power (FP)" which is measured by the node's participation within the whole forwarding process. FP of a node is increased if the node's participation is increased.
- Each node has its global rank to define its global centrality (popularity) across the whole system. This metrics determines the popularity of a node among different communities.
- We choose 7 days as epoch duration for detecting communities. This will cause messages to exist different epochs before expiring for a different number of communities changes for message undelivered during re-clustering.

The Algorithm 1 shows that a node may come across two situations, one is the intra-communication of node and another is the inter-communication of node within the whole system.

### 3.3.1 Intra-communication of Nodes

This is the first part of our algorithm. This type of communication is occurred when a node belongs inside a local community. In this type of communication current node and destination node belong to the same community. For this intra-communication we also consider forwarding power (FP) of the node that means the participation of a node for communication process. FP of node will be used to make forwarding decision. If the FP of encounter node is higher than the FP of current node, then the message will be forwarded. If the condition is not satisfied then the node will keep the message until its get the suitable node or until TTL of the message is expired. FP is calculated by the equation i.in this Equation g(x, y, t) =1 if an interaction is occurred between nodes x and y in the time interval t and otherwise it becomes 0. Here c means the community.

$$\forall\ (c, x) FP(x) = \sum y \exists c(x) \sum_{t=0}^{t} g(x, y, t) \qquad (4)$$

### 3.3.2 Inter-communication of Nodes

When a node is looking for a destination at the global level, then this type of communication occurs. And this is the second part of our algorithm. In inter-communication source node and destination node belong to two different communities. For this type of communication, a node keeps forwarding messages until is finds a suitable node that belongs to the destination community. When a node find a node of destination community, then the current node will transfer the message to the encounter node. In order to forward message to a suitable node within a global system, when a node meets another node, the message will transfer to encounter node if FP of encountered node is higher than the FP of current node or the global rank (popularity) of encountered node is higher than the global rank of current node. Equation of Global Popularity is shown in Equation (5) and it is same as that in [8]. If none of these conditions are satisfied then the node will keep the message until its get the suitable node or TTL of message is expired. For inter-communication we use global popularity concept for the BUBBLE algorithm and FP from the following equation (5) and (6) respectively. For equation (6) we consider $c' \neq c(x)$.

$$\forall\ (x) GP(x) = \sum y \nexists c(x) \sum_{t=0}^{t} g(x, y, t) \qquad (5)$$

$$\forall\ (c', x) FP(x) = \sum y \exists c'(x) \sum_{t=0}^{t} g(x, y, t) \qquad (6)$$

```
Algorithm 1:
Foreach(encounter_Node_i)do
if(communityof(current_Node)==communityof
   (destination_Node))
{
    if(communityof(encounter_Node_i)==communityof
     (destination_Node)
    && FPof(encounter_Node_i)>FPof(current_Node))
       {
       Encounter_Node_i.Add.Message To Buffer(Messages);
        }
}
else
{
   if(communityof(encounter_Node_i)==communityof
   (destination_Node) || FPof(encounter_Node_i)>FPof
   (current_Node)||global_rank_of(encounter_Node_i)>
   global_rank_of(current_node))
      {
        Encounter_Node_i.Add.Message To Buffer(Messages);
       }

}
```

Figure 3.1 EER Algorithm

## 3.4 Dataset

PSN employs human beings for carrying information. That means PSN mainly works with human behaviors. So we have to select a dataset that consider this issue. For our experiments we select SASSY dataset [68] because this dataset is a good representative of human behaviors. In this dataset twenty-five participants were equipped with 802.15.4 Tmote Invent sensors, and they are tracked for 79 days. We augment the trace as detailed in [69], resulting in a dense trace of encounters between participants. Social network information was obtained from Facebook friendships: friendship in the defence scheme corresponds to Facebook friendship. We made a new dataset named as Synthetic SASSY by following SASSY dataset. We find out the nodes who are available in frequent contact. Synthetic SASSY is made by following the probability of a node to present in the contact pattern. We made this dataset in order to evaluate the performance of our algorithm for a large system. Synthetic SASSY dataset is 210 days long with 25 participants. Table 3.1 represents a details about our dataset and our set of inputs for our experiments. As PSN is a new emerging research magnet that has been attracting researchers. So suitable dataset for our experiments are not available. Here firstly we use SASSY dataset which is only 79 days long, then in order to evaluate the performance of our algorithm for a large system we made the synthetic dataset which is named as Synthetic SASSY.

| Dataset Details | | | Input of Experiments | |
|---|---|---|---|---|
| SASSY | Days | participants | Metrics | Ranges |
| | 79 | 25 | TTL (s) | 3600-1296000 |
| Synthetic SASSY | 210 | 25 | Messages | 5000 - 30000 |
| | | | Buffer Size | 100-500 |

Table 3.1 Dataset Analysis

## 3.5 Simulation Setup

This section represents an analysis of our custom simulator. In order to evaluate different forwarding algorithms, we develop our custom simulator. This simulator was simpler and could be more focused than existing simulators ONE [70]. Our custom simulator has three main phases. First phase is clustering. As our algorithm EER is mainly community based routing algorithm, so we firstly detect the communities among the nodes. As we discussed earlier, the community concepts actually come from the human society and PSN mainly works with human beings. That means in PSN information are carried by human beings. So, in our custom simulator we start with clustering that means detecting the communities among different nodes throughout the entire network. Communities among different nodes are characterized by frequent contact. We also discussed earlier that there are different clustering algorithms for detecting communities. Here for EER we implement Louvain algorithm [33] for community detection. The working principle of Louvain clustering algorithm is already discussed before in chapter 2. So in the first phase of our custom simulator we work with Louvain algorithm for detecting communities among all the nodes throughout the whole network. In figure 3.7 shows a flow diagram of our custom simulator which start with data analysis. In case of data analysis we divide the whole dataset with an epoch duration of 7 days that helps to exists messages to stay in different epoch so that undelivered messages can delivered properly. With this epoch duration we divide the SASSY dataset into 11 weeks and the synthetic dataset is divided into 30 weeks. Then we apply our clustering algorithm. We already mentioned that Louvain algorithm is used for detecting communities. By applying this algorithm we get the following view of network during one epoch duration.

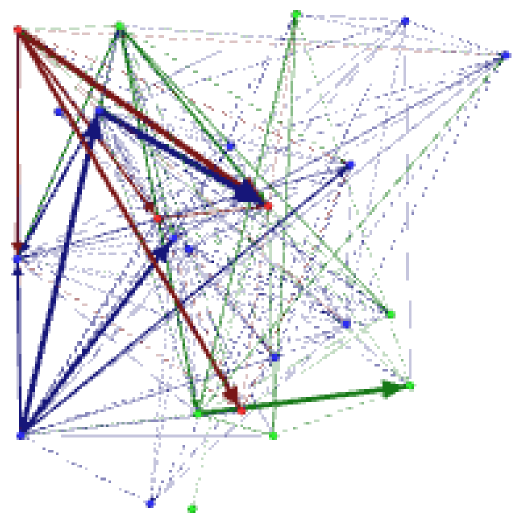

Figure 3.2 Sassy dataset after clustering on one epoch

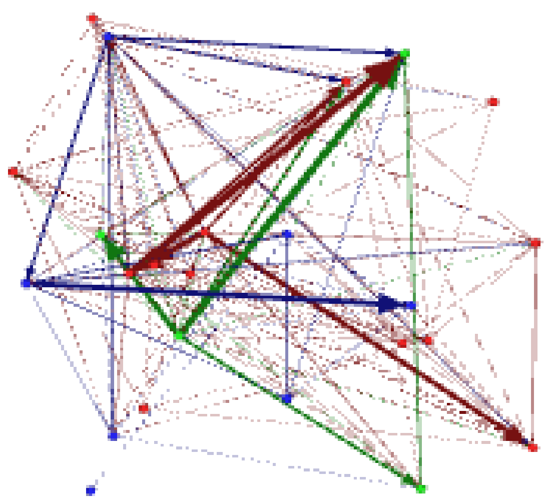

Figure 3.3 Synthetic Sassy dataset after clustering on one epoch

Second phases, of our custom simulator is message generation. Here we generate messages that will be routed throughout the entire network.

```
if(msg_ID<1000){
 if (randomnumber1 == 2) {

        for (int i = 0; i < randomnumber1; i++) {
            Message[msg_ID] = new M1();
            int MsgSource = rndNumbers.nextInt(maximum - minimum + 1);
            int MsgDestination = rndNumbers.nextInt(maximum - minimum + 1);
            while (MsgSource == MsgDestination) {
                MsgDestination = rndNumbers.nextInt(maximum - minimum + 1);
            }
            Message[msg_ID].source =MsgSource;
            Message[msg_ID].destination = MsgDestination;
            Message[msg_ID].carrier = MsgSource;
            Message[msg_ID].TTL = TTL;
            Message[msg_ID].generation_time=(time-1)*604800+week;
            Message[msg_ID].total_delay_time=false;
             msg_ID++;

        }
```

Figure 3.4 Message Generation

Each messages contains source node, destination node, carrier node and Time to Live (TTL). During the time of message generation source node and destination node are chosen randomly for the total forwarding process. We also ensure that for the same message source node and destination node are unique. Here carrier node means the node that are carrying the messages and as a message is routed for one node to another node, the carrier of the message is also changed until the message is reached to its desire destination. Each of the messages has its TTL (indicate the time a message will alive) that is assigned during the time of message generation. Figure 3.4 shows the code for message generation where each unique messages are generated that will be forwarded throughout the whole network. According to the code source node and destination node are randomly selected but they are unique from one another. During the time of message generation the source node will be the carrier node of a message. Whenever a message is transmitted from one node to another then the message carrier node is changed. For the total forwarding process the TTL of each unique messages varies from 1hr to 15 days. We also calculate the message generation time during the time of message generation.

Third part of the simulator is routing. In this part different routing algorithms are implemented and the performance of those routing algorithms are also evaluated. Here we implement four routing algorithms direct pass, flooding, Bubble and EER. We evaluate the overall performance of these four routing algorithms and compare EER with the others. We develop our custom simulator by using JAVA.

```
if ((node_info[time-1][Message[k].carrier][1] == node_info[time-1][Message[k].destination][1])) {

   if ((node_info[time-1][node_interaction[pos1]][1] == node_info[time-1][Message[k].destination][1])
       && (node_forwarding_capability[node_interaction[pos1]][1]>node_forwarding_capability[Message[k]

       Message[k].carrier = node_interaction[pos1];
       Message[k].history = Message[k].history + "" + node_interaction[pos1];
       Message[k].hop++;
             node_forwarding_capability[Message[k].carrier][1]++;
              r_transmission++;


       if (node_interaction[pos1] == Message[k].destination) {

           r_delivermsg++;
            Message[k].r_delivery_time=(time-1)*604800+week;
            Message[k].r_delay=Message[k].r_delivery_time-Message[k].generation_time;
            Message[k].r_total_delay_time=true;
```

Figure 3.5 Intra-communication of EER

Figure 3.5 represents the code of EER for intra-communication. As we discussed before for intra-communication EER consider FP of a node. Here EER firstly check whether the current node and destination node are in the same community. Then it checks whether the encounter node and destination node are in the same community and the FP of the encounter node must be greater than the FP of the current node. Each time a node is selected as a carrier of a message the FP of the node is increased and that will help a node to deliver messages successfully to its desire destination. Each time the message is transmitted from one node to another the total transmission is increased. Finally when the encounter node meet the desire destination then the message is delivered.

```
if ((node_info[time-1][node_interaction[pos1]][1] == node_info[time-1][Message[k].destination][1])
      || (node_info[time-1][node_interaction[pos1]][3] > node_info[time-1][Message[k].carrier][3])
||(node_forwarding_capability[node_interaction[pos1]][1]>node_forwarding_capability[Message[k].carrier][1])


    Message[k].carrier = node_interaction[pos1];
    Message[k].history = Message[k].history + "" + node_interaction[pos1];
    Message[k].hop++;
    node_forwarding_capability[Message[k].carrier][1]++;
     r_transmission++;

    if (node_interaction[pos1] == Message[k].destination) {
        r_delivermsg++;
         Message[k].r_delivery_time=(time-1)*604800+week;
         Message[k].r_delay=Message[k].r_delivery_time-Message[k].generation_time;
         Message[k].r_total_delay_time=true;
```

Figure 3.6 Inter-communication of EER

Figure 3.6 represents the code for inter-communication of EER. As we discussed before for inter-communication EER consider FP or the global popularity of a node. In case of inter-communication the current node and destination node are in different community. We already discussed before that FP of a node can be calculated by the participation of node in the total forwarding process. The global popularity of a node is calculated by the popularity of the node in different communities. That means when a node meet with a node of another community the global popularity of the node is increased. According to EER, it checks either the FP of the encounter node must be greater than the FP of the carrier node or the global popularity of the encounter node must be greater than the global popularity of the carrier node. For inter-communication EER consider either FP or global popularity of node is considered that will help a node to deliver messages successfully to its desire destination. Each time the message is transmitted from one node to another the total transmission is increased. When the encounter node meet the desire destination node then the message is delivered. So the total number of delivered message is increased.

The following flow diagram shows the details about the working principle of our custom simulator. Firstly we start with dataset analysis. We already discussed our two datasets in section 3.4. We analyzed our dataset according to requirement of our simulator. In our dataset analysis we consider the interaction among different nodes and their interaction time. Then the first phase of our simulator starts that is known as clustering and already discussed before. After that the second and third phases are start respectively. Finally, we analyze the results of our all the experiments. This is overall working principle of our custom simulator.

Figure 3.7 shows the flow diagram of our custom simulator which starts with data analysis. This flow diagram gives a clear conception of the working principle of our custom simulator.

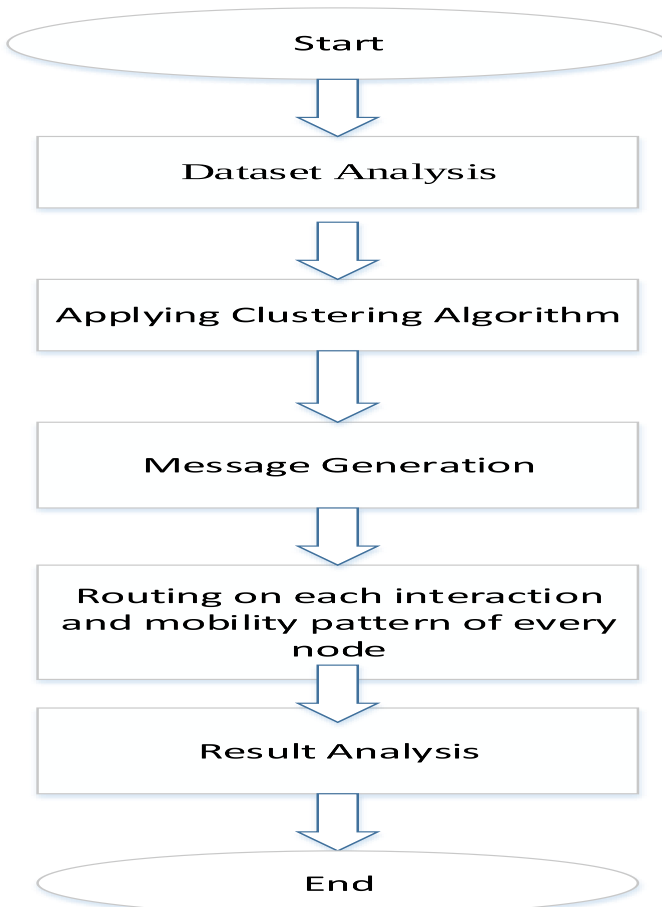


Figure 3.7 Flow diagram of our custom simulator

### 3.6 Comparing Algorithms & Metrics

In our total work we proposed a community based energy efficient routing algorithm named as EER and we compare EER with BUBBLE, Direct Pass algorithm and Flooding algorithm. According to direct pass algorithm a message is delivered only when the desire destination is met otherwise the message is stored to the node buffer. This algorithm provides higher delay to deliver message than other algorithms.

```
Direct Pass Algorithm
Foreach message_M do,
If(Destinationof(message_M)== EncounteredNode_i)
EncounteredNode_i.addmessageToBuffer(message)
else
CurrentNode_i.addmessageToBuffer(message)
```

Figure 3.8 Direct Pass Algorithm

And according to Flooding algorithm messages are flooded throughout the whole system. That means messages are flooded to each and every node of the system and if desire destination is met then the message is delivered and other nodes dropped the messages from their buffer. Flooding algorithm provides higher delivery ratio. As this algorithm floods all the messages throughout the whole system so this algorithm provides higher transmission cost.

```
Flooding Algorithm
Foreach message_M do,
Flood message_M to all EncounteredNode_i
If(Destinationof(message_M)== EncounteredNode_i)
EncounteredNode_i.addmessageToBuffer(message)
else
EncounteredNode_i.DropmessageFromBuffer(message)
```

Figure 3.9 Flooding Algorithm

```
Bubble Algorithm
foreach EncounteredNode_i do
if (LabelOf(currentNode) == LabelOf(destination)) then
if (LabelOf(EncounteredNode_i) == LabelOf(destination))
and
(LocalRankOf(EncounteredNode_i) > LocalRankOf(currentNode))
then
EncounteredNode_i.addMessageToBuffer(message)
else
if (LabelOf(EncounteredNode_i) == LabelOf(destination)) or
(GlobalRankOf(EncounteredNode_i) > GlobalRankOf(currentNode))
then
EncounteredNode_i.addMessageToBuffer(message)
```

Figure 3.10 Bubble Rap Algorithm

Figure 3.10 represent the pseducode of Bubble Rap algorithm. This algorithm mainly work with the local centrality and global centrality of a node. For intra-communication Bubble consider local centrality or local rank of a node and for inter-communication it considers global centrality or global rank of a node. The working principle of BUBBLE algorithm is already discussed in chapter 2 in details.

For all emulation of our work we have measured the following metrics:

- **Delivery ratio:** Delivery ratio is an important metrics for our experiment. This metrics helps to identify the performance of an algorithm. This delivery ratio is measured by the ratio of number of delivered messages to the total number of unique messages created.
- **Transmission Cost:** Transmission cost is measured by the number of hop a message is travelled to reach the desire destination node. That means total transmission cost is measured by the transmission of messages across the whole network.

- **Delay:** In our system firstly we have generated unique messages and then the message is delivered according to the algorithm. Then delay is measured by the time between the message generation and message delivery.
- **Packet Drop:** As messages are stored in the buffer of the node and each node buffer has a particular storage limitation. When the node buffer becomes full then the older messages are dropped and the total number of dropped packet is known as Packet drop. So, Packet drop is measured by the number of packet dropped because of overflow of node buffer.
- **Energy Efficiency:** In our system messages are transmitted among different nodes until the message is delivered to its desire destination. Nodes energy is lost because of this message receiving and transmission process. Here we measure the remaining energy of nodes with respect of time.

# Chapter 4: Results and Discussion

In this chapter we will discussed about our different set of experiments and their results to evaluate the performance of EER and represent a comparison with different algorithm. We mainly develop EER as an improvement of Bubble-Rap [8] proposed by Hui et al. which considers the popularity of individual nodes within communities. Although Bubble-Rap algorithm is mainly proposed for delay tolerant networks (DTN), but it considers community concept. Authors of Bubble have used different dataset for their experiments that are suitable for DTN. We already mention that we propose EER for PSN, so the charactertics of dataset that we use for our experiments are different. So in this chapter we will represent only our experimental results of these algorithms. Here we consider three scenarios for measuring the performance of EER and the other comparing algorithms. For each scenario we measure delivery ratio, transmission cost, delay and packet drop. In order to evaluate the performance of EER in case of energy efficiency we measure the remaining energy of nodes with respect to time.

## 4.1 Scenario 1

For the scenario 1 we consider three inputs No of messages, node buffer size and TTL of the message. Here for scenario 1 we have fixed number of messages to 1000 and node buffer size is 10% of the total number of messages but TTL of the messages varies from 1hr to 15 days. The following table shows the details about the set of inputs for the scenario 1.

| Inputs | Range of Values |
|---|---|
| No of messages | 1000 |
| Node buffer | 10% |
| TTL | 1hr – 15 days |

Table 4.1 Input details for scenario 1

### 4.1.1 Delivery Ratio

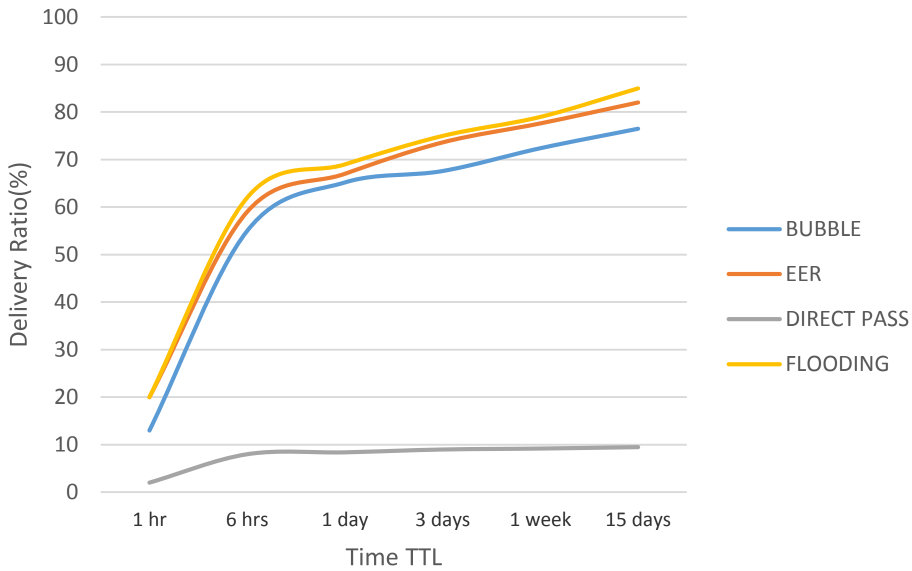


Figure 4.1.1.a SASSY

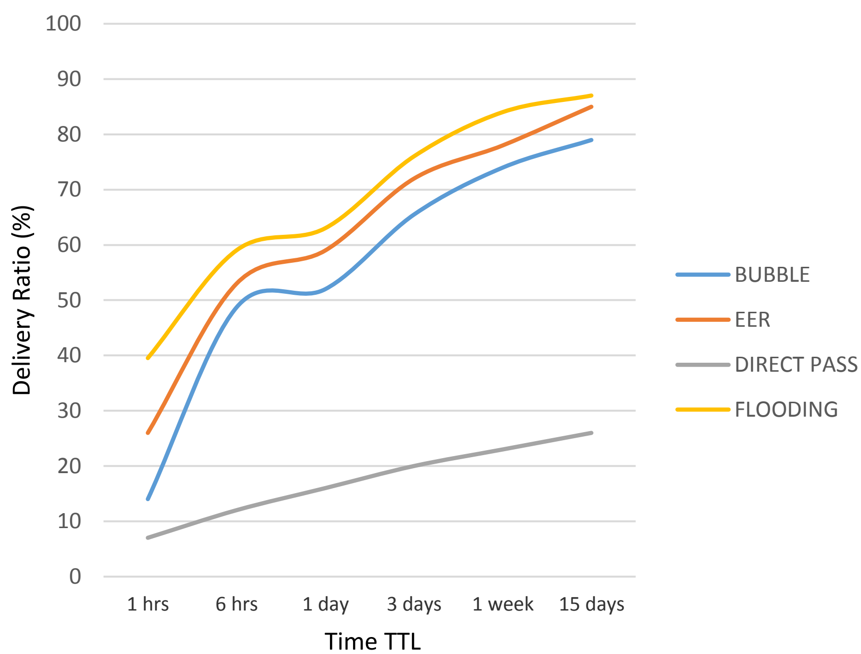


Figure 4.1.1.b Synthetic SASSY.

Figure 4.1.1.a and 4.1.1.b shows comparison of several algorithms with EER on delivery ratio with respect to TTL. TTL has a prominent role to increase the delivery ratio of messages for different algorithms.

Here in case of SASSY dataset, according to figure 4.1.1.a we can see EER has 11.95 % higher delivery ratio than Bubble. But Flooding has the highest delivery ratio which is 9.5% higher than EER. According to figure 4.1.1.b, for Synthetic SASSY dataset EER has 8.44% higher delivery ratio than Bubble but Flooding has the highest delivery ratio which is 2.8% higher than EER. For both dataset, we can see that EER has better performance than Bubble but flooding has the highest delivery ratio.

### 4.1.2 Transmission Cost

We can see in Figure 4.2.2.a and 4.2.2.b, the impact of TTL to change the cost of message transmissions for different algorithms with the same set of inputs of table 4.1.

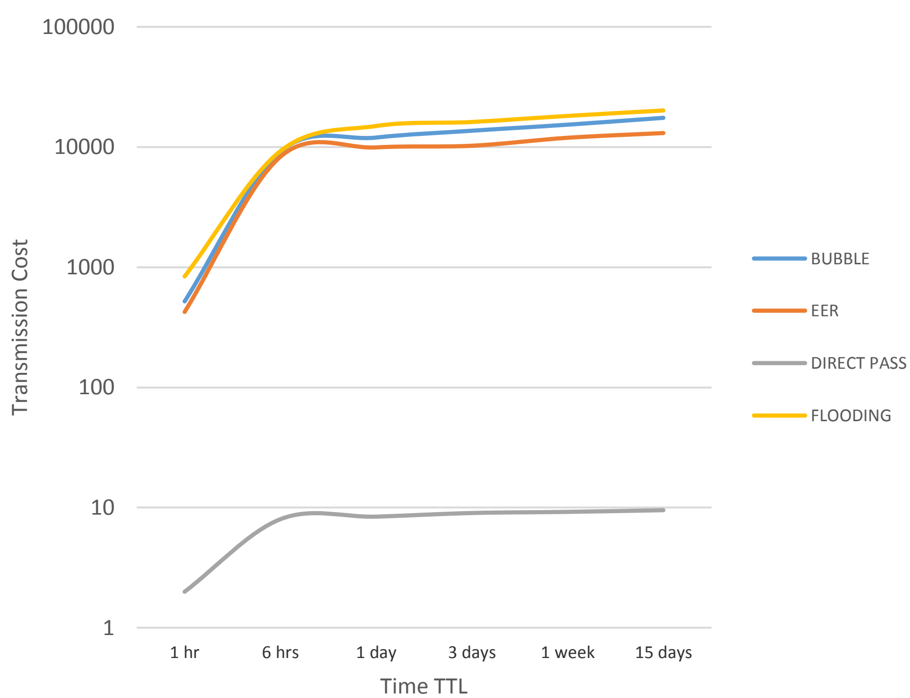


Figure 4.1 2.a SASSY

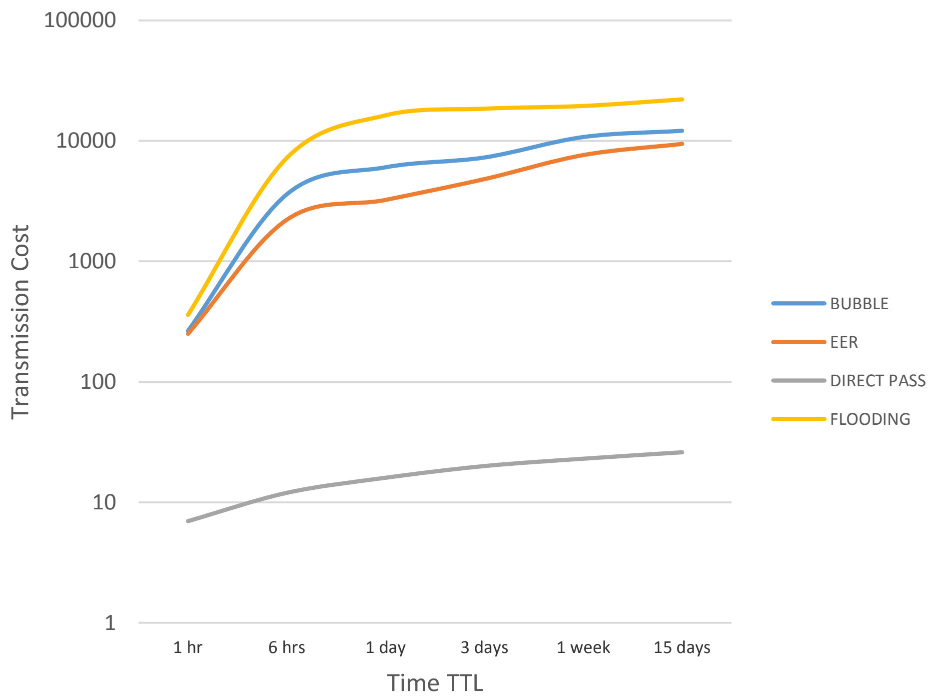


Figure 4.1.2.b Synthetic SASSY

In figure 4.1.2.a we can see that Bubble has 26.8 % higher transmission cost than EER. But Flooding has the highest transmission cost which is 16.8% higher than Bubble. According to figure 4.1.2.b Bubble has 45.03% higher transmission cost than EER. In that case Flooding has also the highest transmission cost which is approximately 2.098 times higher than Bubble.

### 4.1.3 Delay

The output of figure 4.1.3.a and figure 4.1.3.b shows the impact of TTL on the average delay of message delivery for different algorithms. According to figure 4.1.3.a for SASSY dataset we observe that Bubble has 60% higher average delay than EER and Direct pass algorithm has the highest average delay and which is 11.92% higher than Bubble. For Synthetic SASSY dataset, according to figure 4.1.3.b Bubble has approximately 2.05 times higher average delay than EER and Direct pass algorithm has 24.48% higher average delay than Bubble.

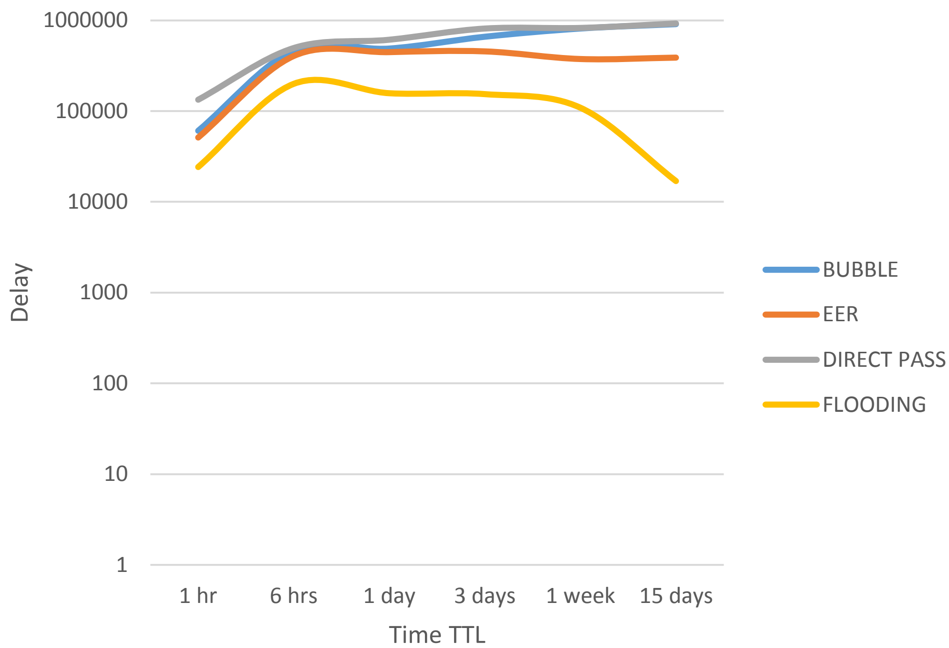


Figure 4.1.3.a SASSY

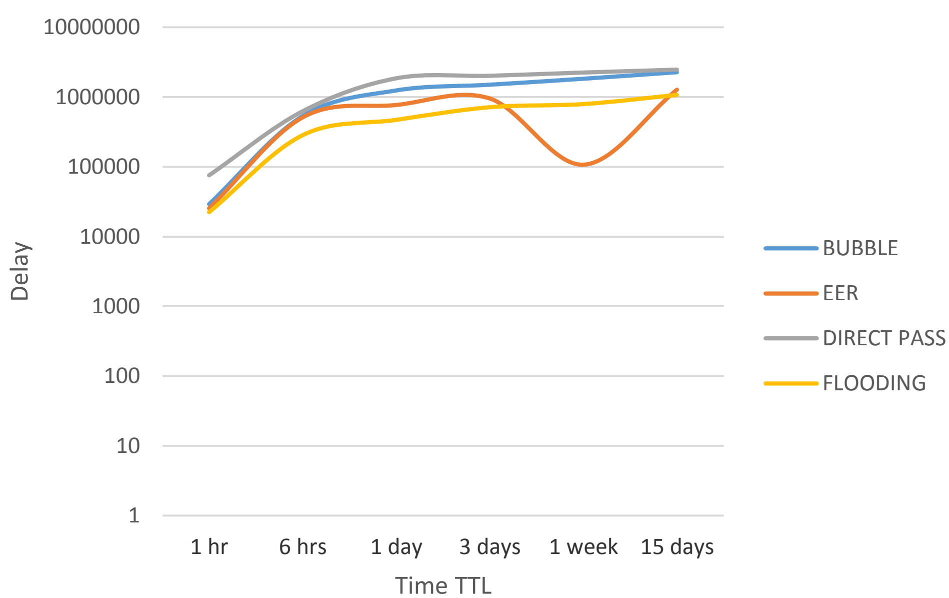


Figure 4.1.3.b Synthetic SASSY

### 4.1.4 Packet Drop

According to figure 4.1.4.a and 4.1.4.b we get almost same result both for SASSY and Synthetic SASSY dataset. In every case we observe that both of BUBBLE and EER has the almost same amount of packet drop in average. For this reason we have used both the line graph and bar graph to represent the result clearly. But in case of flooding algorithm, it has the highest amount of packet drop.

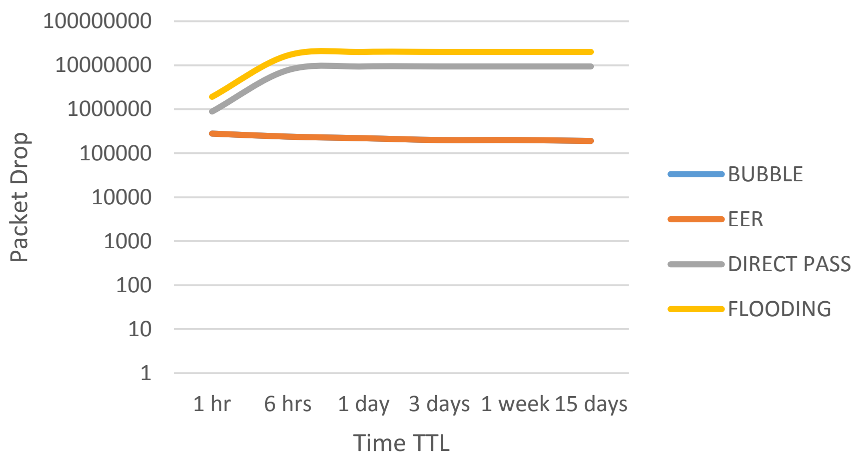


Figure 4.1.4.a SASSY

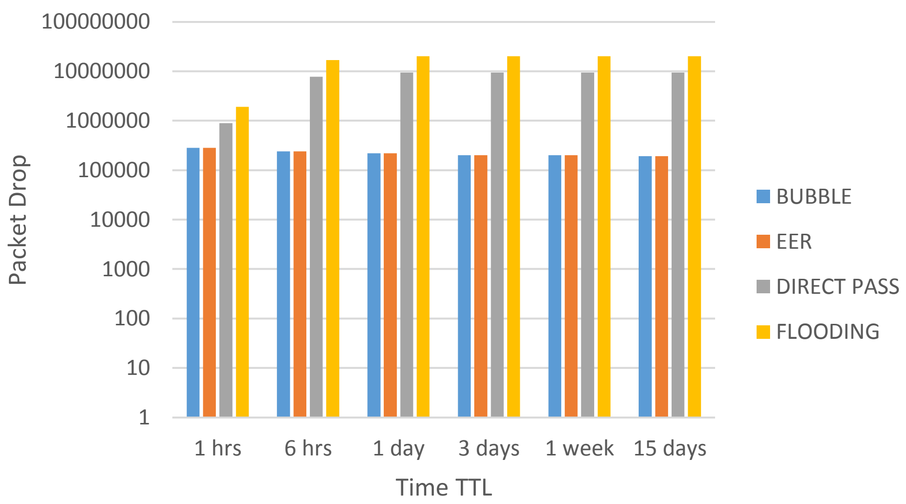


Figure 4.1.4.a.1 SASSY

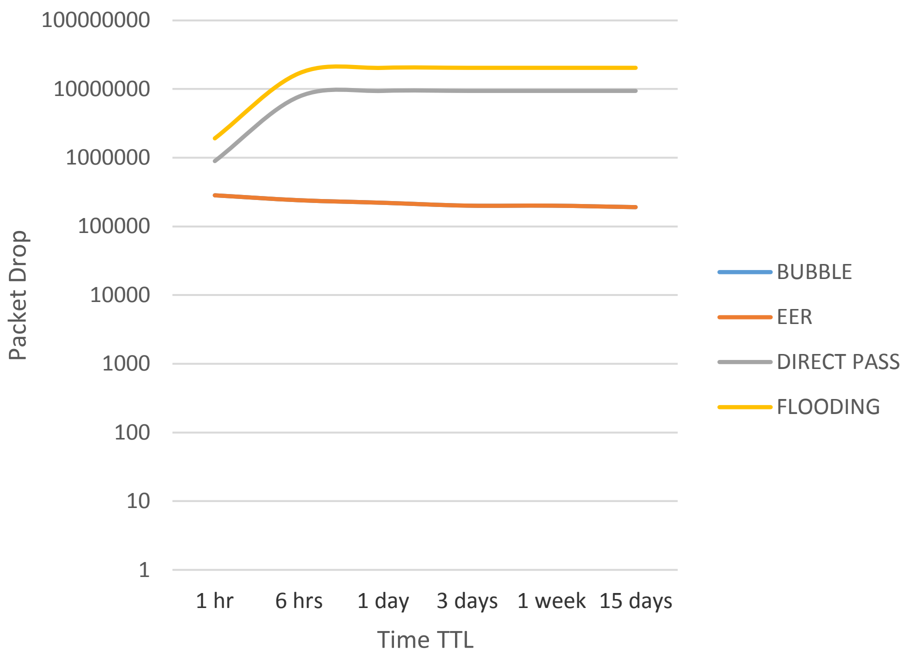


Figure 4.1.4.b Synthetic SASSY

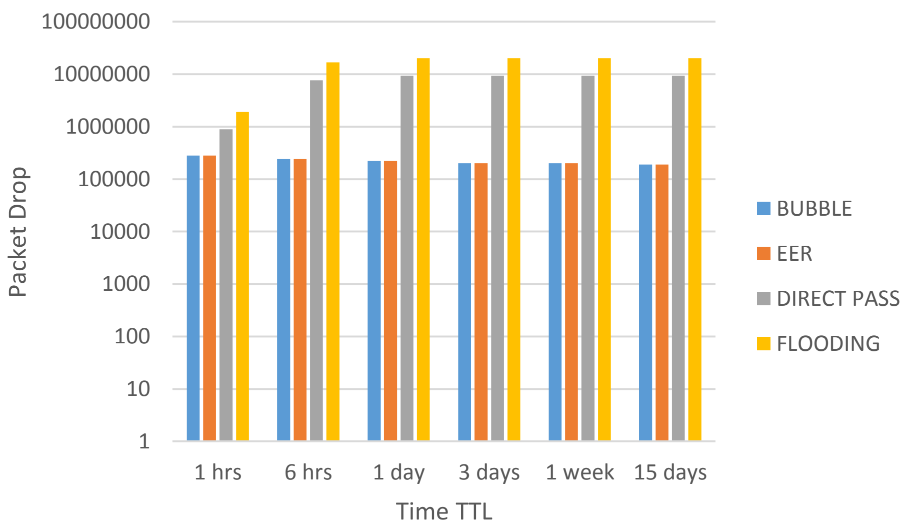


Figure 4.1.4.b.1 Synthetic SASSY

## 4.2 Scenario 2

For the scenario 2 we have fixed TTL of messages and node buffer size but number of message varies. The following table shows the details about the set of inputs for the scenario 2.

| Inputs | Range of Values |
|---|---|
| No of messages | 5000 - 30000 |
| Node buffer | 10% |
| TTL | 1week |

Table 4.2 Input details for scenario 2

### 4.2. 1 Delivery Ratio

Figure 4.2.A.a and 4.2.A.b shows comparison of EER with other algorithms with varying number of messages.

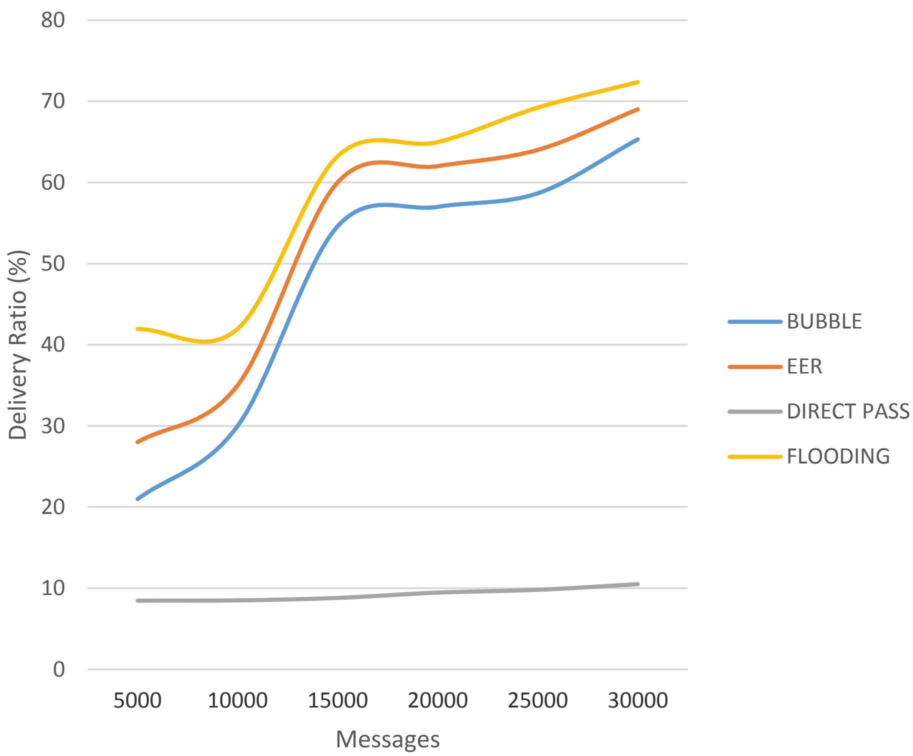


Figure 4.2.1.a SASSY

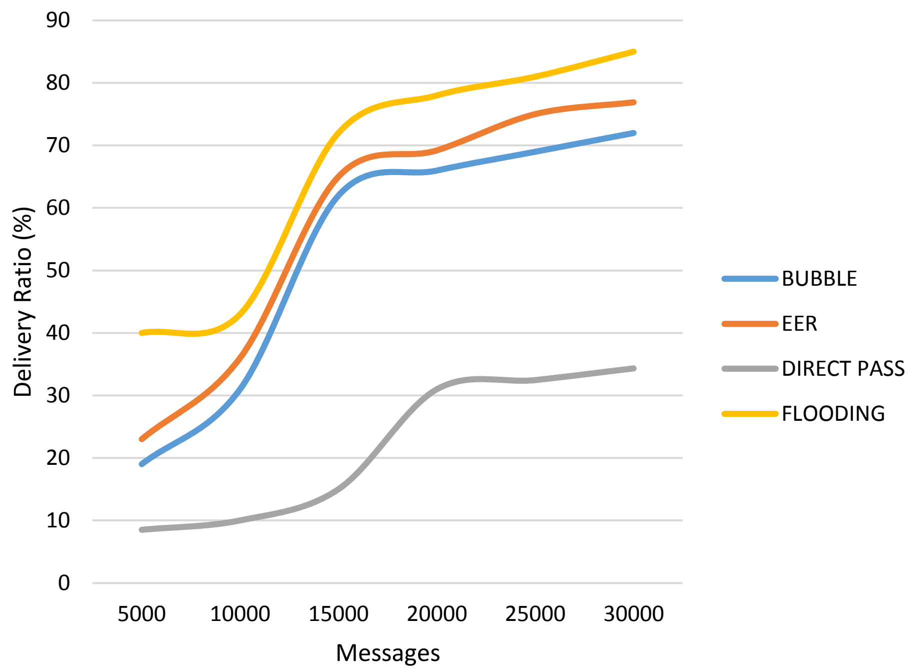


Figure 4.2.1.b Synthetic SASSY

Here in figure 4.2.1.a for SASSY dataset, EER has 11% higher delivery ratio than Bubble with various number of messages. But Flooding has the highest delivery ratio which is 11.3% higher than EER. According to figure 4.2.1.b for Synthetic SASSY EER has 8.18% higher delivery ratio than BUBBLE and Flooding has the highest delivery ratio which is 15.61% higher than EER.

### 4.2.2 Transmission Cost

In order to evaluate the performance of EER on transmission cost metric we do the following experiments with the same set of inputs of table 4.2.

We observed that in figure 4.2.2.a for SASSY Bubble has 7.08 % higher transmission cost than EER and Flooding has 6.64% higher transmission cost than Bubble. For figure 4.2.2.b ,with Synthetic SASSY dataset Bubble has 39.62% higher transmission cost than EER and Flooding has 41.7% higher transmission cost than Bubble. So we can see that both for SASSY and Synthetic SASSY dataset EER has the lower transmission cost than other algorithms and Flooding has the highest transmission cost.

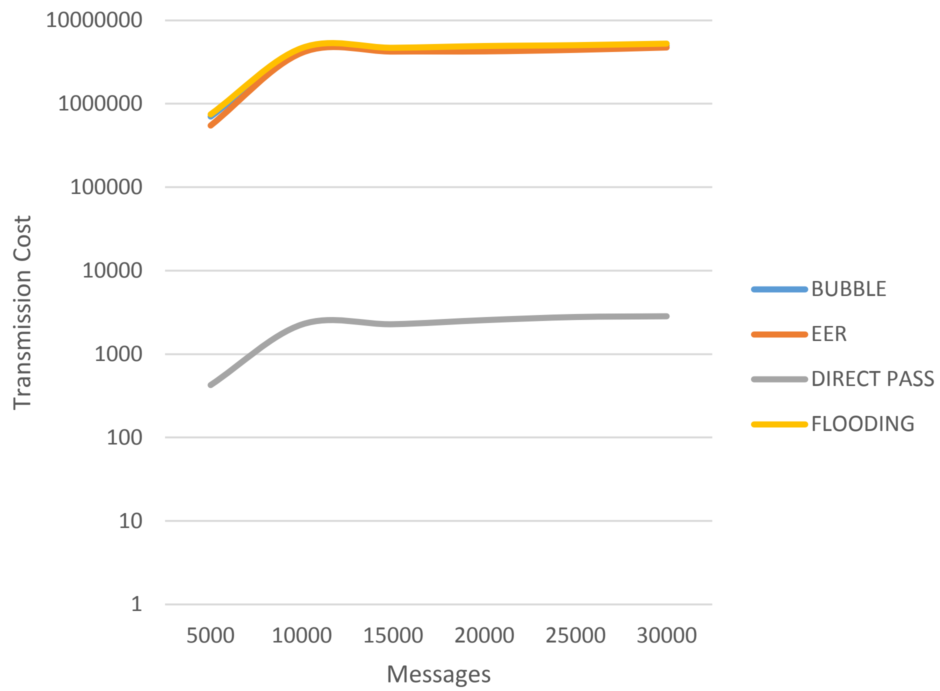


Figure 4.2.2.a SASSY

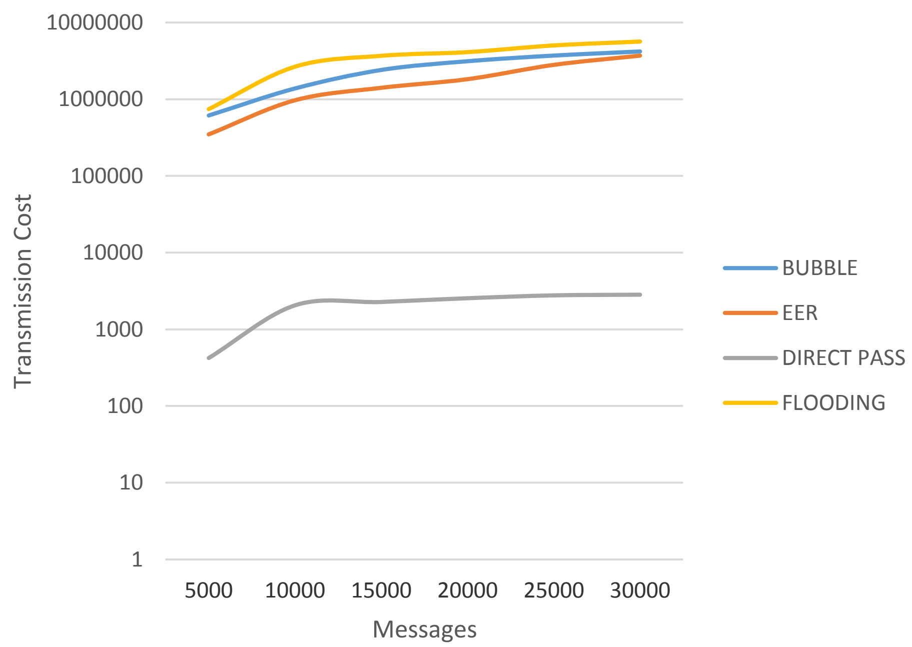


Figure 4.2.2.b Synthetic SASSY

### 4.2.3 Delay

In order to measuring delay of EER and comparing with different algorithm we have execute the following set of experiments with the inputs of table 4.2.

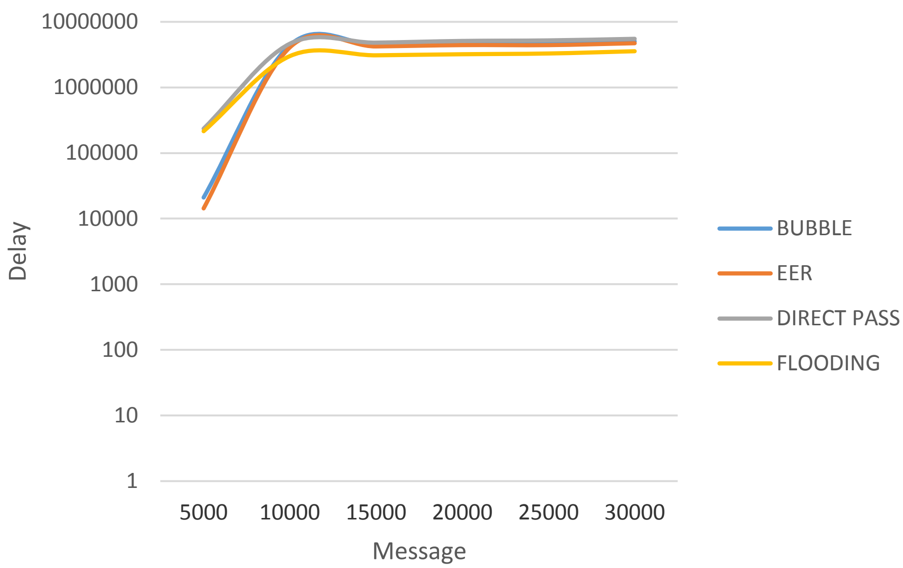


Figure 4.2.3.a  SASSY

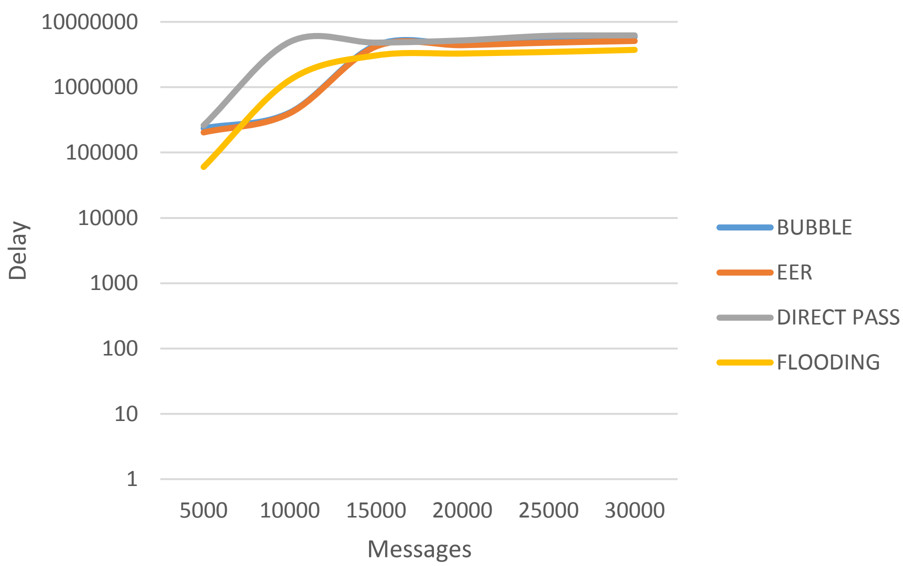


Figure 4.2.3.b  Synthetic SASSY

For figure 4.2.3.a Bubble has 6.05% higher average delay than EER and Direct pass algorithm has 10.37% higher average delay than Bubble. Acording to figure 4.2.3.b we observed that Bubble has

8.56% higher average delay than EER and Direct pass algorithm has 32.64% higher average delay than bubble.

### 4.2.4 Packet Drop

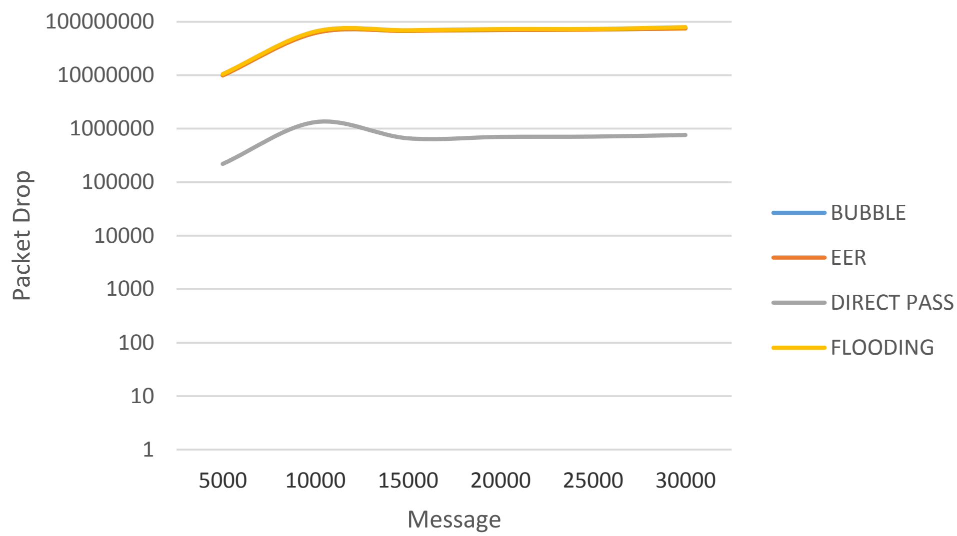


Figure 4.2.4.a SASSY

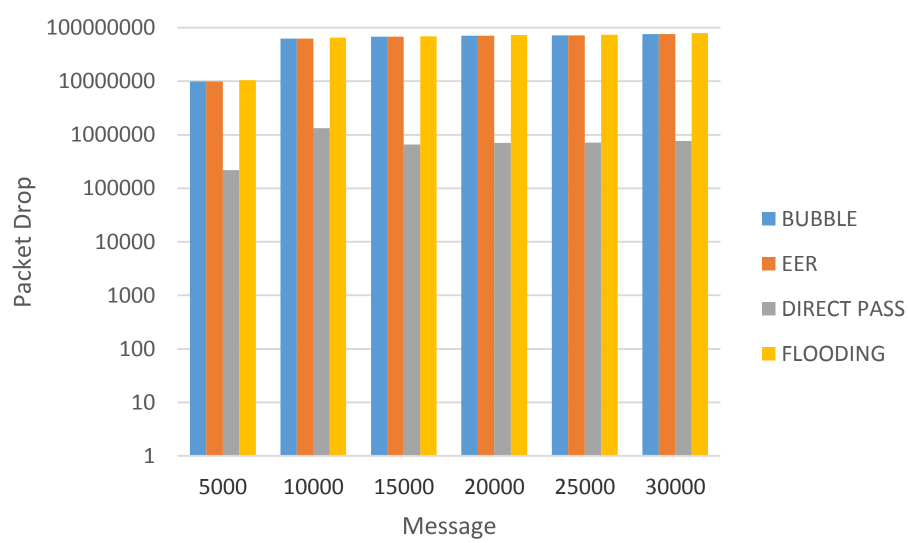


Figure 4.2.4.a.1 SASSY

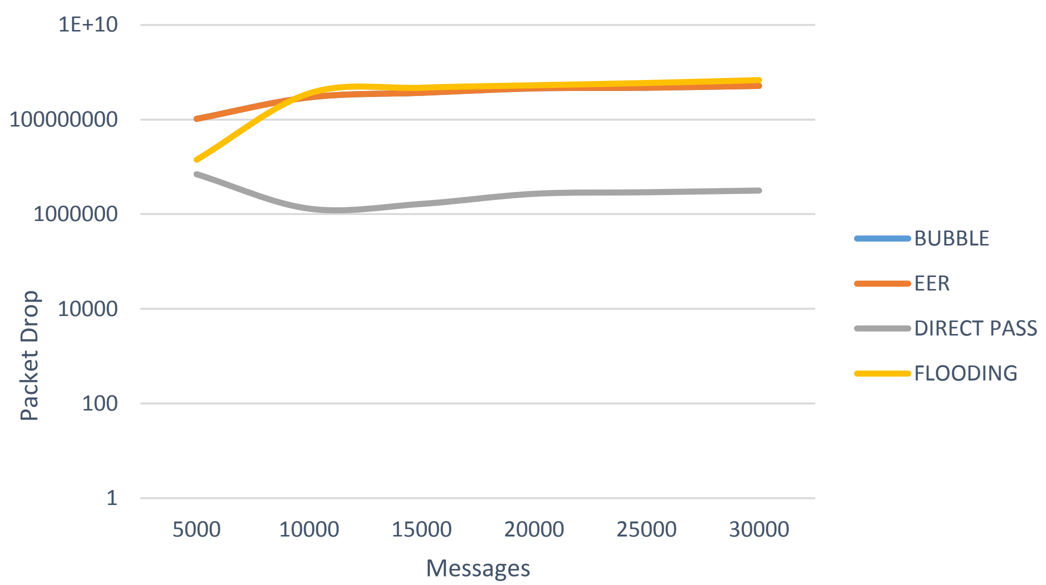


Figure 4.2.4.b Synthetic SASSY

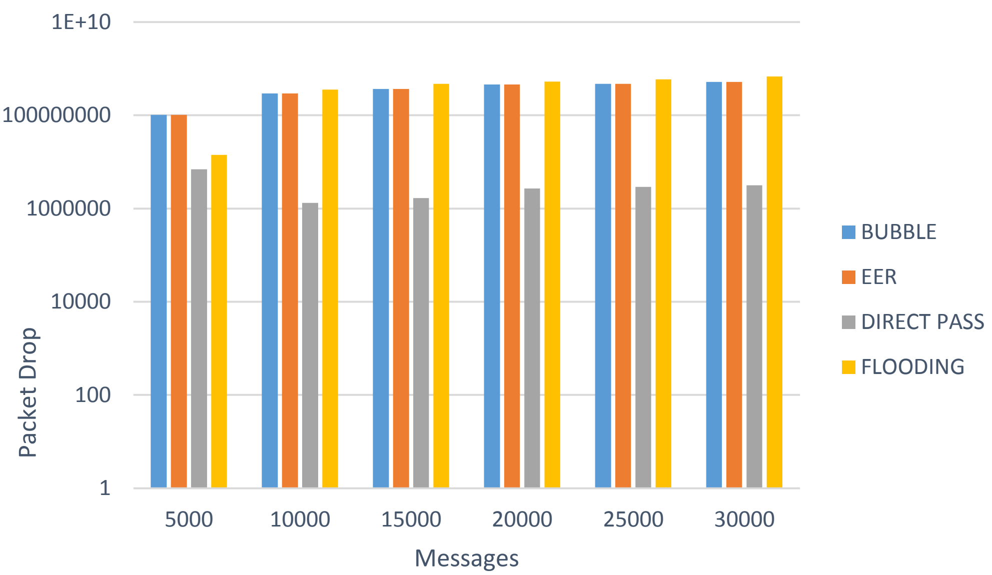


Figure 4.2.4.b.1 Synthetic SASSY

According to figure 4.2.4.a and 4.2.4.b we get almost same result both for SASSY and Synthetic SASSY dataset. For scenario 2 we observe that both of BUBBLE and EER has the almost same amount of packet drop in average. For this reason we have used both the line graph and bar graph to represent the result clearly. But in case of flooding algorithm, it has the highest amount of packet drop.

## 4.3 Scenario 3

For the scenario 3 we have fixed TTL of messages and number of messages but node buffer size varies. The following table shows the details about the set of inputs for the scenario 3.

| Inputs | Range of Values |
|---|---|
| No of messages | 1000 |
| Node buffer | 10% -50% |
| TTL | 1week |

Table 4.3 Input details for scenario 3

### 4.3.1 Delivery Ratio

We have execute the following set of experiments with the inputs of table 4.3 for scenario 3.

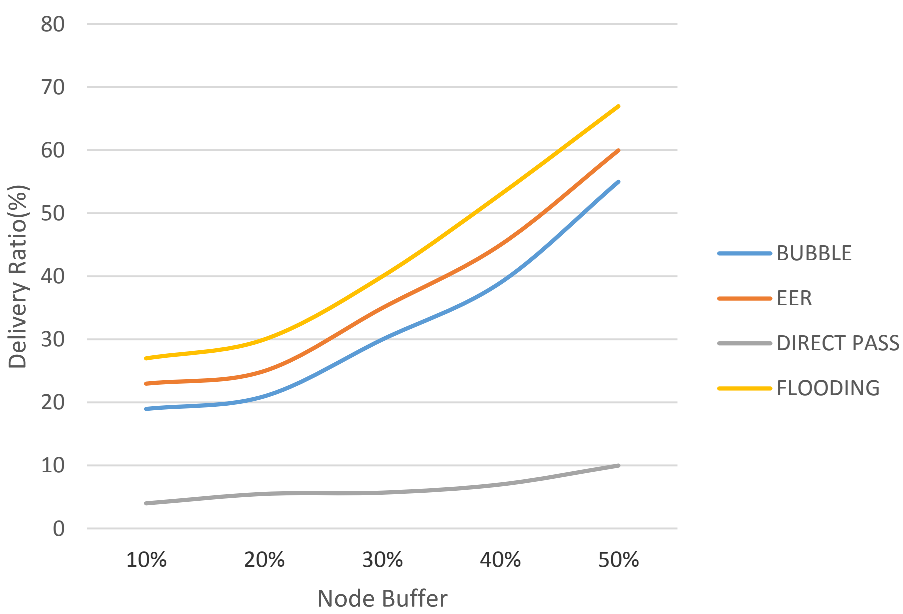


Figure 4.3.1.a SASSY

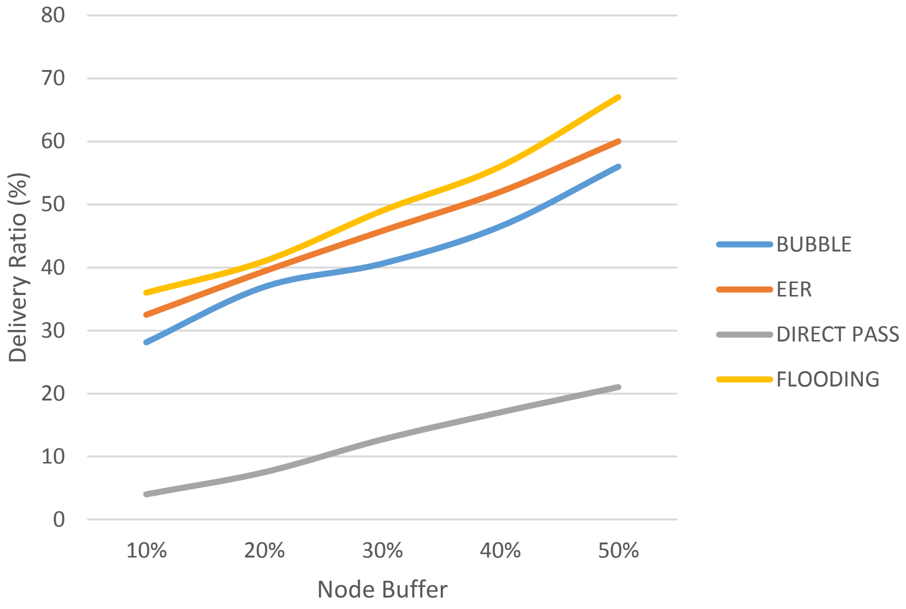


Figure 4.3.1.b Synthetic SASSY

Then we see in 4.2.1.a for SASSY EER has 14.63 % higher delivery ratio than Bubble. But Flooding has the highest delivery ratio which is 15.42% higher than EER. For Synthetic SASSY dataset, according to figure 4.2.1.b EER has 10.37% higher delivery ratio than Bubble but flooding has 8.4% higher delivery ratio than EER.

**4.3.2 Transmission Cost**

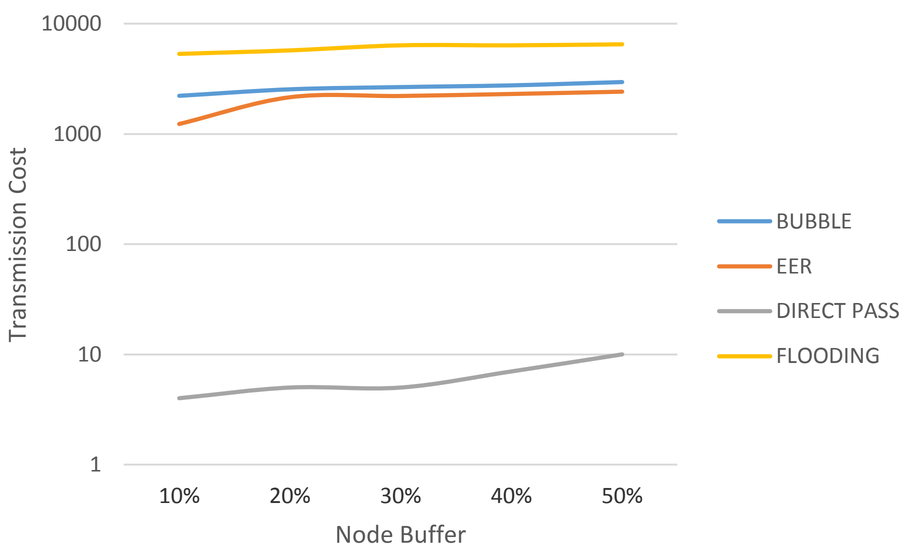


Figure 4.3.2.a SASSY.

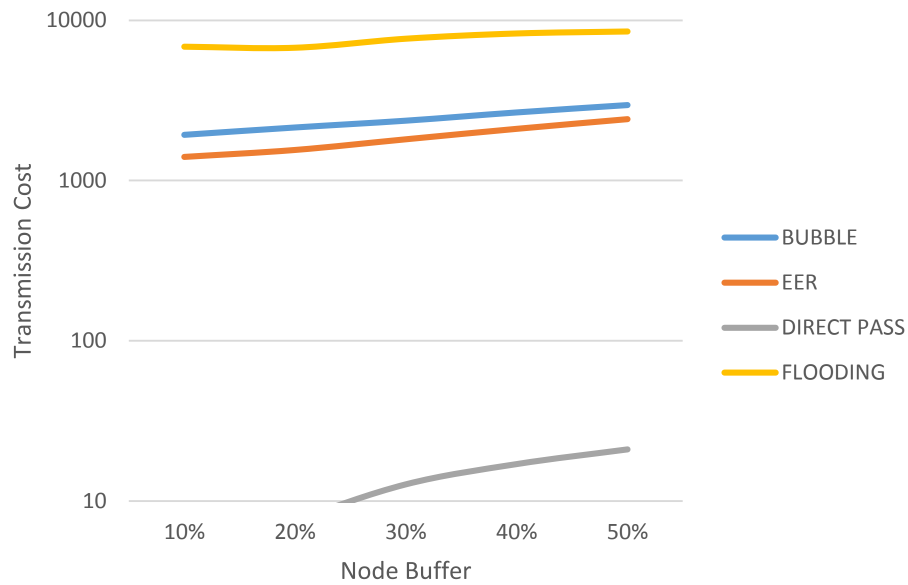


Figure 4.3.2.b  Synthetic SASSY

Both for figure 4.3.2.a and 4.3.2.b we consider the same set of outputs of table 4.3. Here we get for figure 4.2.B.a  Bubble has 27.3% higher transmission cost than EER and Flooding has 2.304 times higher than Bubble. For figure 4.2.B.b Bubble has 29.6% higher transmission cost than EER and Flooding has 3.15 times higher transmission cost than Bubble.

### 4.3.3 Delay

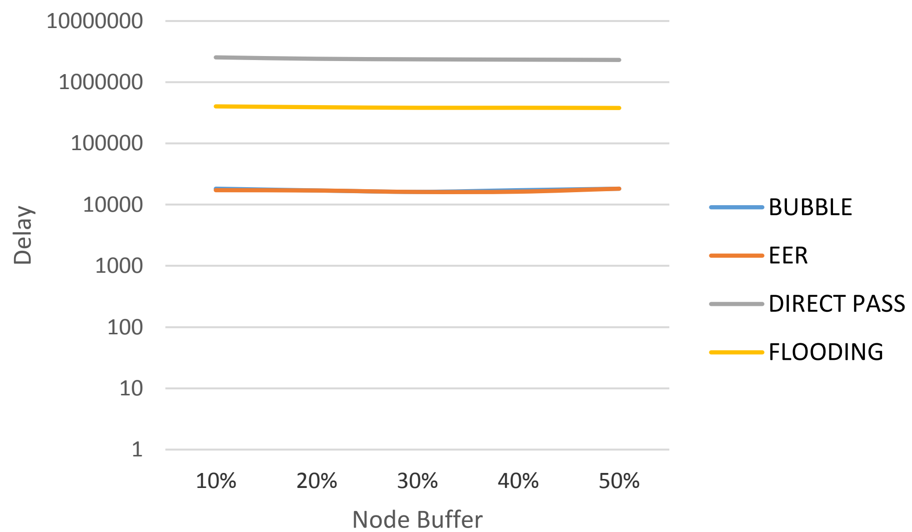


Figure 4.3.3.a  SASSY

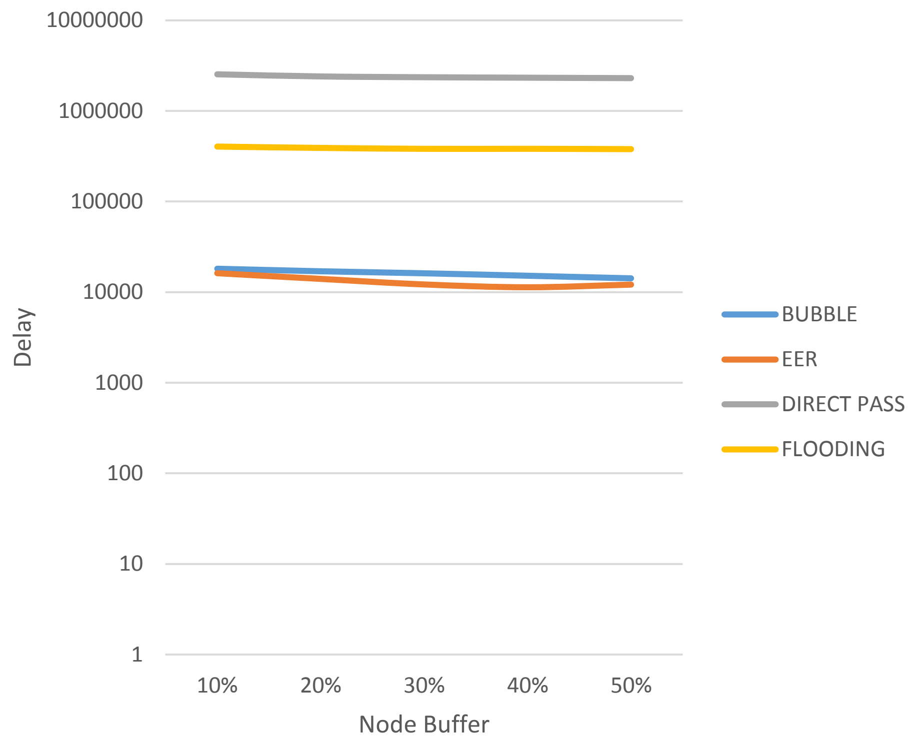


Figure 4.3.3.b Synthetic SASSY

Here both for figure 4.3.3.a and 4.3.3.b we consider the inputs of table 4.3. For the SASSY dataset of figure 4.3.3.a we observed that Bubble has 2.44% higher average delay than EER but Direct pass algorithm has 137.6 times higher average delay than Bubble. And for Synthetic SASSY dataset of figure 4.3.3.b we can see that Bubble has 22.97% higher average delay than EER but Direct pass algorithm has the highest average delay which is 147.73 times higher than Bubble.

### 4.3.4 Packet Drop

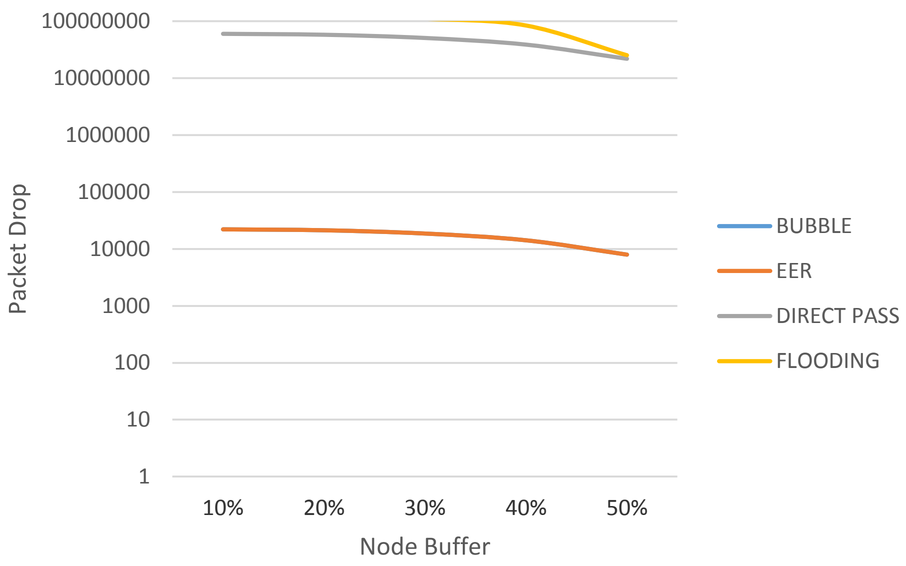


Figure 4.3.4.a SASSY

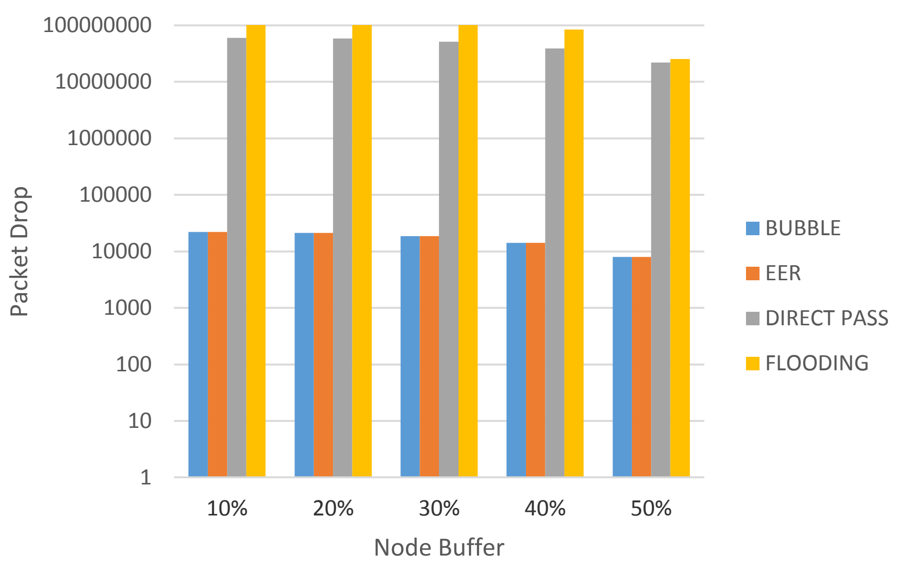


Figure 4.3.4.a.1 SASSY

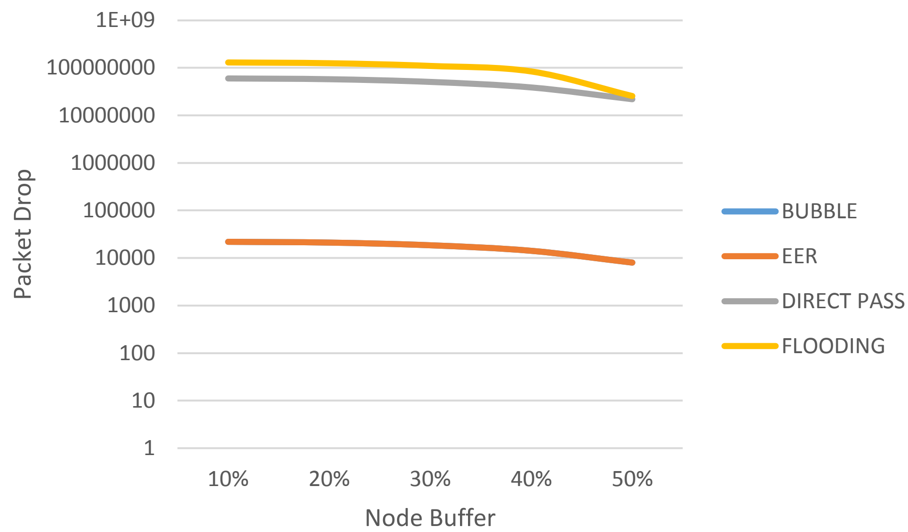


Figure 4.3.4.b  Synthetic SASSY

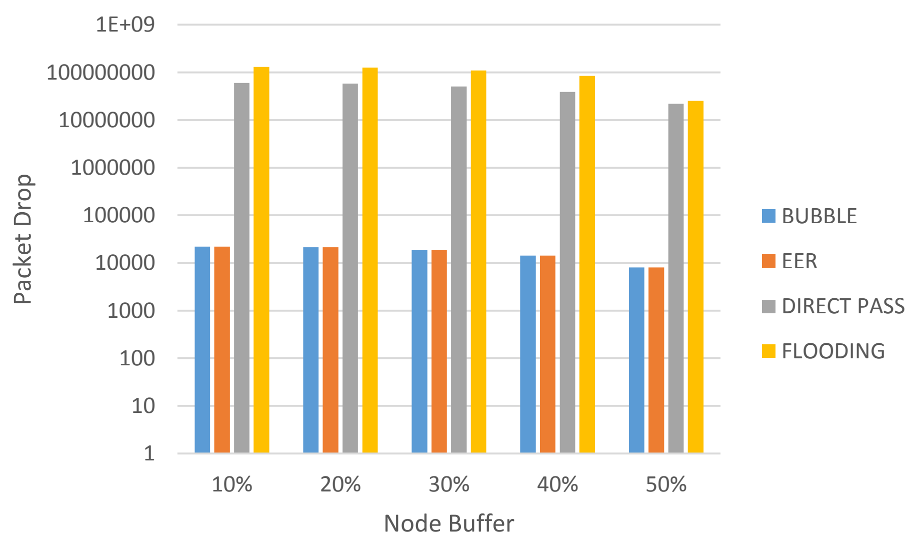


Figure 4.3.4.b.1  Synthetic SASSY

According to figure 4.3.4.a and 4.3.4.b  we get almost same result both for SASSY and Synthetic SASSY dataset. For scenario 3 we observe that both of BUBBLE and EER has the almost same amount of packet drop in average. For this reason we have used both the line graph and bar graph to represent the result clearly. But in case of flooding algorithm, it has the highest amount of packet drop.

## 4.4 Energy Efficiency

Mobile devices like smart phones, laptops, PDA etc. that are carried by human beings in different places with high number of nodes and high contact density. Such environment can occur in any conference, office space etc. These type of environments are the example of PSN. But these mobile devices that are carried by human beings have very limited energy. For rapid and reliable data transmission it becomes unreasonable to utilize large amount of energy. Existing PSN routing protocols do not consider low energy consumption in their design objectives. So energy consumption is a major factor in the performance of the whole network. In PSN the amount of energy of a node is considered as an important factor in sending and receiving messages. So it is important to consider the remaining energy of a node. In PSN when a node encounter another node either the node receive messages from the encounter node or transmit messages to the encounter node. In both cases a node loss some energy. In our thesis we consider this issue. We calculate the remaining energy of nodes with respect to time and then compare the performance of our proposed algorithm EER with other algorithms. For each node of our entire system we consider initially they have X unit of energy. When the node encounter another node and send messages to the encounter node, then the current node will loss x unit of energy. When the current node receive messages from the encountered node the current node loss y unit of energy. Table 4.4 shows the energy setting of nodes. For our experiment we assume that initially a node has 5000 units of energy, each time the node transmit data it losses 1 unit of energy and each time it receives data it losses 0.9 unit of energy.

| Parameter | Values (Units) |
|---|---|
| Initial _energy | 5000 |
| Transmit _energy | 1 |
| Receive_energy | 0.9 |

Table 4.4 Nodes energy setting

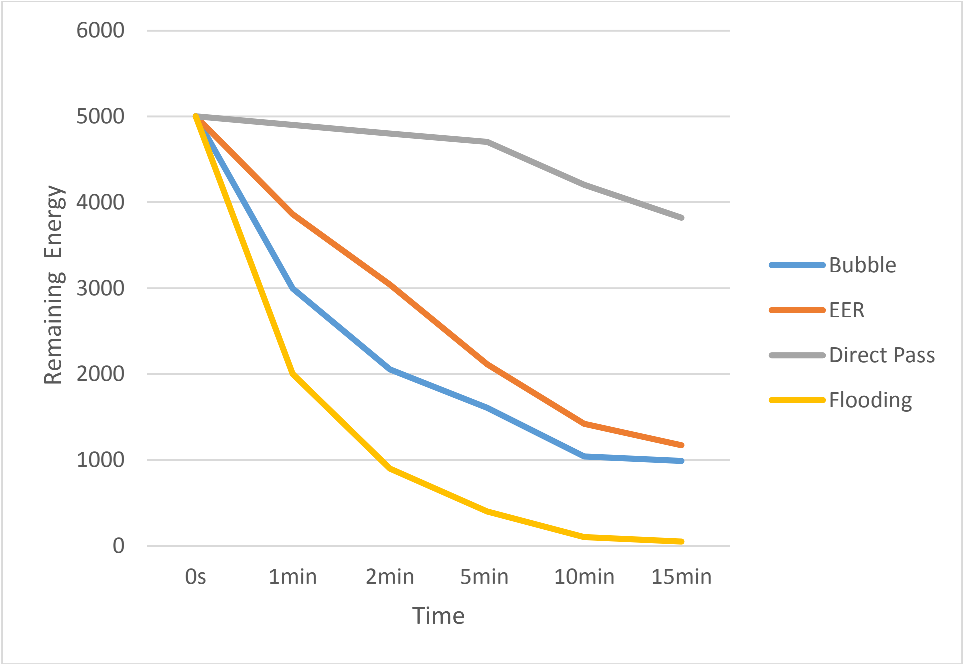


Figure 4.4.1 Remaining Energy for SASSY

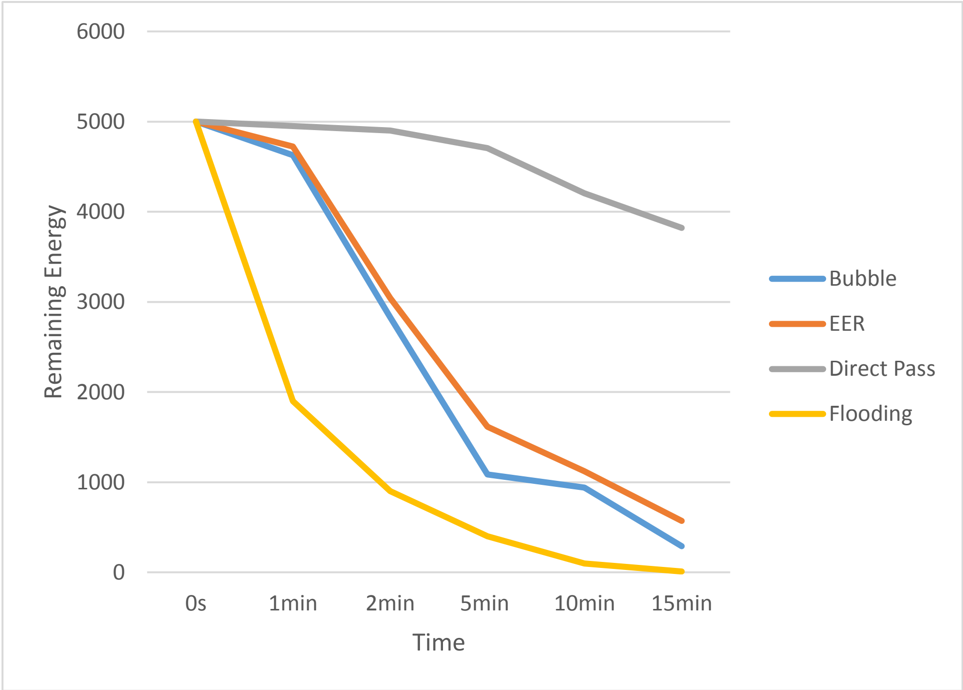


Figure 4.4.2 Remaining Energy for Synthetic SASSY

Figure 4.4.1 and 4.4.2 shows the overall results of remaining energy of node for SASSY dataset and Synthetic SASSY dataset respectively. Here we can observe that the remaining energy of nodes are reducing with time. We follow table 4.4 for the setting of node energy for both of the dataset. According to figure 4.4.1 we observed that the performance of EER is better than Bubble and flooding. EER selects only some selected nodes for effective data forwarding. We already discussed before that EER consider FP or global popularity of nodes for successful message transmission. These helps to save nodes energy. In case of flooding nodes consume much energy than other algorithms because in flooding each message is transmitted to all the encountered node and that needed much energy consumption. That's why nodes energy become almost zero with time. On the other hand in case of direct pass highest unit of energy remaining with time. As in direct pass messages are only transmitted only when the desire destination is met. That's why it saves energy of nodes. Direct pass algorithm has saved much energy than the other algorithms. According to figure 4.4.2 we observed that the performance of EER is better than Bubble and flooding. But for the synthetic SASSY dataset nodes are consumed much energy than SASSY dataset. As Synthetic SASSY is a long dataset with high contact density, so number of message receiving and transmitting is also high. If a node participate in receiving and transmitting of messages, it will loss certain unit of energy. In case of Synthetic SASSY as node participation is high, much energy is consumed by nodes. For this reason in case of Synthetic SASSY nodes are consumed much energy than SASSY.

## 4.5 Discussion

According to the above discussion for every scenario we observe that EER has higher delivery ratio, lower transmission cost and lower average delay than Bubble.But in case of packet drop EER and Bubble has the same perfomance. Our future work may consider this issue.

EER achieve higher delivery ratio than Bubble because in order to take forwarding decision we consider FP for intra-communications and for inter-communications we consider either FP or global popularity. As we discussed, earlier FP is measured by the participation of node throughout the whole system. FP of a node is increased when it carries messages. And for inter-communications, we consider either FP or global popularity which is measured by the popularity of a node in global community. These metric help EER to increase the amount of successfully delivered messages and also increases the overall delivery ratio for the whole system. But we can see here, EER performs better for SASSY dataset but for Synthetic SASSY EER has approximately lower performance. As Synthetic SASSY dataset is larger than SASSY that may reduce the performance of EER over Synthetic SASSY.

We observe that both for SASSY and Synthetic SASSY dataset EER has lower transmission cost than Bubble. But Flooding has the highest transmission cost. For Synthetic SASSY EER has lower transmission cost than SASSY.As Synthetic SASSY has larger amount of interactions than SASSY which helps to reduce the transmission cost. As we discussed earlier EER selects only some particular nodes (having high FP or Global popularity) as relay nodes for successful deliver of messages to the desired destination. That causes minimum hop count, so overall transmission cost is reduced.

Here we can observe that both for SASSY and Synthetic SASSY dataset EER has the lower delay than Bubble and Direct pass has the highest average delay than the other algorithms. For Synthetic SASSY EER has the lower average delay than SASSY. As Synthetic SASSY dataset is 210 days long and we have large amount of interactions which may help EER to reduce the average delay. According to EER it becomes eassy to identify the proper relay node by using node information for succesfull delivery of each message.That reduces the difference between the message delivered time to the message generation time. So overall average message delivered delay is reduced.

As these above experiments are different in their parameter but we get almost same result both for SASSY and Synthetic SAASSY dataset. In every case we observe that both of BUBBLE and EER has the same amount of packet drop in average because for both of the algorithms packet drop is measured by the overflow of node buffer. But in case of flooding highest amount of packet is expired.

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# Chapter 5: Conclusion and Future Work

In this thesis, we present an Energy Efficient routing protocol (EER) for PSNs which is the overall contribution of this thesis. EER is mainly a community based energy efficient routing algorithm. EER mainly takes forwarding decision by measuring FP of each node. We already discussed before the way of measuring FP of each nodes. For intercommunication EER considers both the global rank and FP. Finally ,EER achieves higher delivery ratio, fast (low-delivery-latency) , and energy efficient (low transmission cost) routing in intermittenty connected PSNs and have better performance than Bubble and other algorithms as we discussed earlier. As EER cannot reduce the amount of average packet drop than Bubble,our future work will focus on this issue. Direct pass algorithm shows better performance than EER for some of the scenarios. This could change when other proposed clustering methods in the literature are used for implementing the proposed new algorithm. As PSN is formed by human beings and most of the time they are intermittenty connected or connection is almost broken. PSN employs mobile nodes. So clustering is difficult in PSN.On the other hand succesful data forwarding among these mobile nodes become challenging and it may be a future scope of research. Most of the routing protocols in PSN are flat. This flat approach is suitable for small network but is not scalable.In future this can be extended to a hierarchical structure in order to develop a scalable approach . The method proposed in this thesis uses clustering may provide better result in making groups among the mobile nodes with similar mobility pattern into same cluster.

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